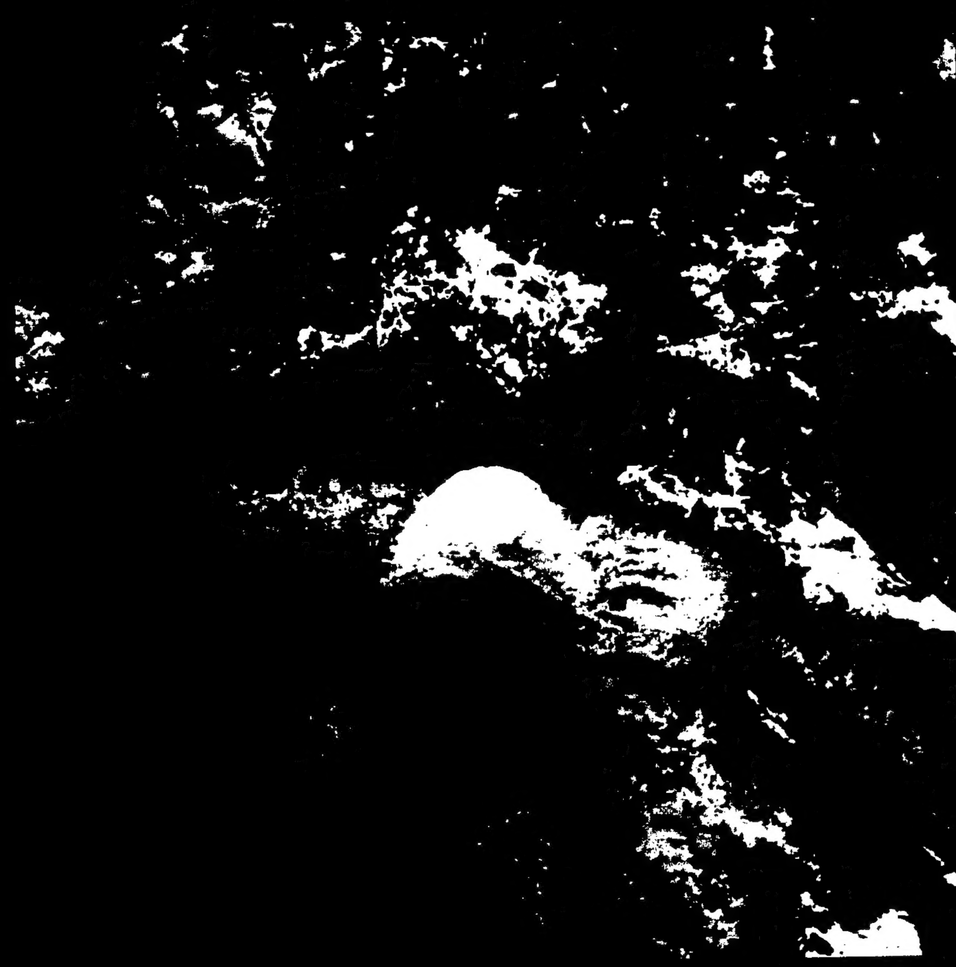
Strategic Scene Generation Model



SSGM Papers Presented at the Meeting of the IRIS Specialty Group on Targets, Backgrounds, and Discrimination

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Authors/Affiliation	Title/Content/Codes
Heckathorn & Anding Naval Research Laboratory (NRL) & Photon Research Associates (PRA) • includes presentation materials	"Overview of the Strategic Scene Generation Model (SSGM)" SSGM Program Description, Requirements, Architecture, Phenomenology, Celestial Backgrounds Codes: CBSD, SKY, ZODY
Anding, Mertz & Fleri Photon Research Associates (PRA)	"Background & Target Plume Models of the Strategic Scene Generation Model" Terrestrial Background (Terrain & Cloud), Missile Plumes, Midcourse Objects, and SSGM Frame Generation Software Codes: GENESSIS, CLDSIM, APART, SPF2, SIRRM, CHARM, OSC, SIGNAT
Armstrong, McKenzie & Saunders Mission Research Corporation (MRC)	"Earthlimb and Aurora Background Scene Generation" Natural LTE & NLTE Atmospheric Radiance, Deterministic/Stochastic Structure, and SSGM Earthlimb/Aurora Submodules Codes: LOWTRAN, APART, HAIRM, ARCHON, SHARC, NLTE, ARCTIC
Blackwell, Stephens, Gomez & Teoh Physical Research, Inc. (PRi)	"Nuclear Backgrounds for SSGM" IR Nuclear Backgrounds, Temporally Correlated Stochastic Structure and SSGM Nuclear Submodule & Data Bases Codes: NORSE, PEM, IRSim, STRCTR

OVERVIEW OF THE STRATEGIC SCENE GENERATION MODEL (SSGM)

January 1990

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ABSTRACT

The Strategic Defense Initiative (SDI) must simulate the detection, acquisition, discrimination and tracking of anticipated targets and predict the effect of natural and man-made background phenomena on optical sensor systems designed to perform these tasks. NRL is developing such a capability using a computerized methodology to provide modeled data in the form of digital realizations of complex, dynamic scenes.

The Strategic Scene Generation Model (SSGM) is designed to integrate state-of-science knowledge, data bases and computerized phenomenological models to simulate strategic engagement scenarios and to support the design, development and test of advanced surveillance systems. Multi-phenomenology scenes are produced from validated codes — thereby serving as a standard against which different SDI concepts and designs can be tested.

This paper describes the SSGM architecture, the software modules and data bases which are used to create scene elements, the synthesis of deterministic and/or stochastic structured scene elements into composite scenes and scene sequences, and the software system to manage the various data bases and digital image libraries. We will discuss the existing Prototype Model (SSGMP) and the design architecture of the fully-functional Baseline Model (SSGMB) which is currently being developed. We will also describe the relationship between this project, the phenomenological models, and proposed data centers to improve access to the relevant empirical data.

1.0 INTRODUCTION

NRL has been given the responsibility by the Sensors Directorate of SDIO for developing the Strategic Scene Generation Model (SSGM) to provide modeled data in the form of digital realizations of complex multi-phenomenology scenes.[1] The SSGM project supports SDIO R&D technology demonstrations and measurements programs (see Table 1) by furnishing valid pre-computed scenes and dynamic scene sequences for specific engagement scenarios and/or the software capability to generate these scenes.

TABLE 1. CURRENT SSGM USER COMMUNITY

PROGRAM	AGENCY	SSGM APPLICATION
BSTS	SD	Standard fixed-frame SWIR & MWIR scenes for hardware demonstrations, digital simulations, and evaluation of system performance predictions (SN)
SSTS	SD	Midcourse LWIR scenes to support system demonstration and validation methodology (SN)
GSTS	ASDC	Requirements similar to SSTS but with target discrimination (SN)
KHILS	AFATL	SSGM software to meet scene data base generation requirements for the Target Scene Generator (KE)
IATACS	WL	Dynamic scenes for the Integrated Acquisition, Tracking and Aimpoint Control System (DE)
AMDF	RADC	SSGM software to generate scene data bases for the Attack Management Development Facility (DE)
NTB	ESD	SSGM software to support NTF system evaluations and simulations (NTB)

SN = Surveillance Sensor, KE = Kinetic Energy, DE = Directed Energy

[1]This work is being performed for NRL by Photon Research Associates (PRA), with subcontractor support from Mission Research Corporation (MRC), Physical Research Incorporated (PRi), The Analytical Science Corporation (TASC), Teledyne Brown Engineering (TBE), and Image Data Corporation (IDC) under contract N00014-89-C-2283.

SSGM products are used to evolve system concepts into preliminary designs, critical designs, and eventually performance test. For example, custom scenes have been created for candidate BSTS sensors and for specific viewing geometries to provide a basis for comparing performance predictions of the two prime contractors (LMSC & GAC). Likewise, SSTS and GSTS programs have indicated that they require precomputed scenes tailored to their specific requirements. These Phase I Surveillance Tracking Satellite systems also require fully operational SSGM software and supporting input data bases to generate end-to-end scene sequences for testing target handover and sensor fusion. The SSGM program currently supports several hardware-in-the-loop system simulations of kinetic and directed energy weapons by providing prototype software and data bases needed by users to specify and generate digital images easily and rapidly (KHILS/TSG and IATACS). These tests include ground demonstrations and simulations wherein scaled sensors perceive and respond to real photometric data generated from digital images produced by the SSGM. Signal injection or in-band scene projection technology are used in these hardware-in-the-loop simulations which will eventually be event-driven. User-generated scenes are also used to populate large data bases required by system test beds and development facilities for exercising and refining algorithms used in target acquisition, aimpoint control and defensive attack management (AMDF & NTB/NTF).

The SSGM is being developed to integrate, for the first time, the various "government-standard" phenomenology codes to provide valid, standard scene data to a community of users. Traditionally, individual phenomenology models allow the user to estimate the nature and importance of observables when it is infeasible to sample all required spatial or temporal resolutions, orientations, or wavelengths. The SSGM is a critical capability which will combine various first principles and semi-empirical codes and data bases into an architecture specific to anticipated SDIO application requirements. Where appropriate, the SSGM will make direct use of existing data archived in one of three Phenomenology Data Centers being developed by the SDIO.[2] This interface will facilitate the validation of SSGM methodology by providing direct access to the relevant empirical data.

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[2]Midcourse Data Center at ASDC in Huntsville, Background Data Center at NRL in Washington, and Plume Data Center at AEDC in Tullahoma.

The SSGM development will occur in three phases, the first of which was completed in February 1989. These are: SSGM Prototype, SSGM Baseline, and SSGM Operational. The Prototype was delivered to NRL, is being utilized by selected government agencies and laboratories, and serves as the foundation for the SSGM Baseline development. The SSGM Baseline is planned for delivery in September 1992. Architecturally, it will be fully responsive to SDIO needs, but will have data base and execution speed limitations. The SSGM Operational model will have a full complement of data bases and achieve execution speeds adequate to support real-near-time hardware-in-the-loop simulations.

Working Groups have been established for both the Strategic Scene Generation Model and Data Management within the User Products Subgroup. User Products is one of three additional Subgroups (Backgrounds, Plumes, Midcourse) which support the Phenomenology Steering and Analysis Group. The PSAG is concerned with the coordination of phenomenology experiment planning and analysis and with model development, use and validation. The formulation of concepts for managing experimental phenomenology data and monitoring the development of an integrated scene generation model are critical PSAG roles.

2.0 SSGM REQUIREMENTS

The scene data needed to support SDIO program elements consists of radiometrics of scene elements plus time-sequenced 2-D scenes of sensor-perspective pixel radiance maps of backgrounds with imbedded targets. The SSGM must represent user-specified scenarios of strategic significance. For example, a satellite-borne surveillance, acquisition, or track sensor may view a boosting missile positioned against an earth horizon background. The specific composition of this scene is constantly changing because the sensor and target are moving along their trajectories, there is drift and jitter in the sensor line-of-sight, and the missile plume emission is itself varying with time.

For general sensor-target-background engagement scenarios, various target and background observables could exist within the scene sequence. Phenomenology associated with targets might consist of the missile hard body, missile plume and target related persistence phenomena (fuel dumps), spent stages, satellites, post-boost

vehicles, re-entry vehicles, decoys, penetration aids, and post-kill debris (including salvage-fused warheads). Backgrounds might include "hard" earth (terrain, ocean, and ocean ice), meteorological phenomena (semi-transparent/opaque clouds), quiescent atmospheric phenomena (scattering/emission/absorption, earth-limb airglow emission), the perturbed atmosphere (aurora and man-made backgrounds including single or multiple nuclear detonations), and celestial sources (zodiacal, galactic, and extragalactic).

The problem confronting the SSGM is to provide such digital scene sequences constrained only by limitations in the physical models and empirical data bases incorporated within on-line phenomenology codes and/or pre-computed data base inputs. The goal is to encompass the totality of spatial, temporal, and spectral sampling regimes set by anticipated SDI sensor system specifications and engagement scenarios. The frame size may range from a few hundred to over a thousand pixels in each dimension and the duration of the scenario may span a hundred or more seconds at a fraction of a second framing rate. The size of the digital scene data base produced may range from several tens to several thousands of megabytes and, when coupled with event-driven simulations, must be produced in reasonable times by a software architecture which is responsive to the external interrupts implicit when unforseen events influence the flow of the simulation. The dynamic range, spectral range, and resolution must also span likely sensor candidates. However, the SSGM does not attempt to model optical or sensor systems which modulate the calculated scene radiance values.

3.0 SSGM ARCHITECTURE

Viewer-perspective digital radiance maps, or scenes, are derived from an ensemble of the best available government standard phenomenology models and authenticated data bases via an interactive software system which selects the required input parameters and executes the pertinent models to generate the scenes specified by the user (see Figure 1).

The SSGM process consists of four major functions (User Input, Sequence Definition, Run-Time Generation, Frame Generation) interfacing with four data base

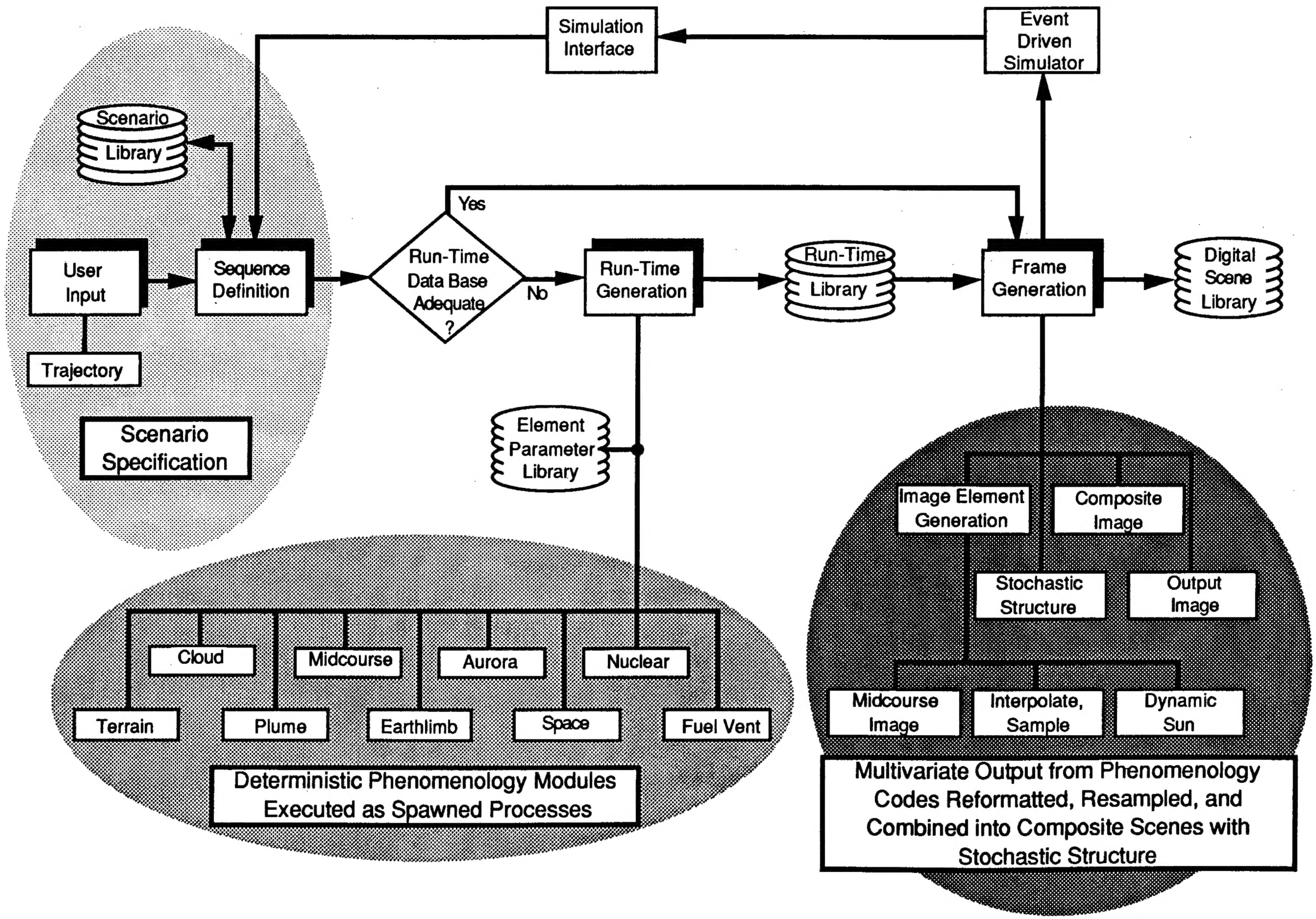


Figure 1. Baseline SSGM Functional Flow Diagram

libraries (Scenario, Element, Run-Time, and Scene). The software modules which accomplish these functions will be described below.

User Input accepts all sensor, background, and target input specifications through an X-Window menu interface. When implemented on a graphics workstation (see Figure 2), User Input will allow the user to actually "build" a scenario interactively. User Input also allows for adding, deleting, and archiving items stored in the data base libraries and for displaying information on these items.

Sequence Definition defines the scene elements, the sensor-background-target engagement geometries, and the scene sampling parameters. The geometric boundaries of the scenario are computed and the associated bounding elements required to perform the scene generation for the defined scenario are determined and stored in the Scenario Library. Specifically, for each pixel of the sensor field-of-view, its location versus time is quantified, as well as the composition of the scene it views. Once the boundaries have been established, Sequence Definition determines whether or not the elements currently exist in the Run-time Library or need to be generated.

Run-Time Generation, supported by nine subfunctions, calculates all additional data needed to generate the scenes defined by Sequence Definition. This is achieved through on-line execution of phenomenology software modules and is only invoked when deficiencies in the Run-Time Library data base are established during Sequence Definition. Inputs to the phenomenology modules are derived from the frame requirements stored in the Scenario Library. Also, the Element Parameter Library contains specific data bases required by the individual phenomenology submodules (*e.g.*, atmospheric chemistry data, materials properties, bidirectional reflectivity functions, *etc.*). The multivariate output from the phenomenology codes populate the Run-Time Library which can be accessed quickly during the process of Frame Generation.

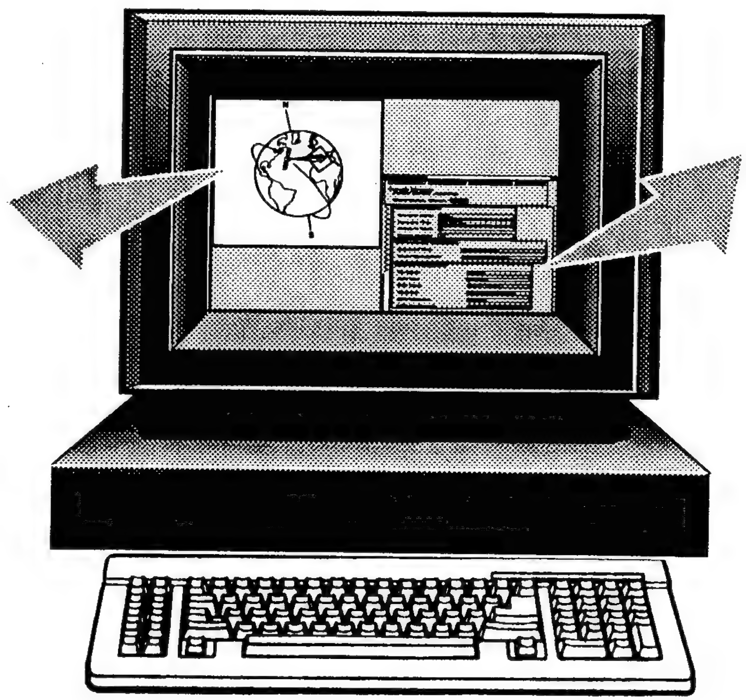
Frame Generation casts Run-Time Library files into image elements which can be spatially and temporally resampled and combined to synthesize composite, multi-phenomenology scenes. Four submodules (Image Element Generation, Stochastic Structure, Composite Image, and Output Image) convert the Run-Time Library data bases into viewer-perspective two-dimensional pixel images. Typically, this involves

I. USER-INTERACTIVE SCENARIO CONSTRUCTION

- Placement of Sensor LOS Direction and FOV Size
- Placement of Background Scene Location
- Placement of Target Launch Position, Trajectory Azimuth, Time of Launch

II. ON-LINE SENSOR TRAJECTORY CALCULATION

- Ballistic
- Orbital



SAMPLE X-WINDOW MENU INPUTS

A. SENSOR
- Trajectory Input Parameters
- Sensor LOS
  - stare (Latitude, Longitude, Altitude)
  - scan (Target Track, "Coolie Hat", other)
- Waveband
- IFOV, #Rows, #Columns
- Begin Time, End Time, Interval

B. BACKGROUND
- Scene ID
- Location (Latitude, Longitude)
- Model Atmosphere

C. TARGET
- Target ID
- Trajectory Input Parameters (option)
- Trajectory Launch Location
- Trajectory Azimuth
- Time of Launch

Figure 2. SSGM X-Window User Interface for Interactive Scenario Construction

interpolating and sampling, but can also involve image generation for hardbody targets, for targets or missile plumes which are being actively illuminated by lasers, and for terrain or cloud backgrounds when they are being illuminated by a "dynamic" sun (*i.e.*, nuclear fireball or missile plume). When the statistics of a random process can be specified from empirical data, the structure of deterministically computed image elements can be modulated independently to simulate the stochastic process. "Deterministic structure" refers to spatial variation in radiance which can be specifically computed from the physics models involved. "Stochastic structure" refers to irregularities in the target or background which cannot be predicted in a deterministic manner, but for which statistics can be generated. The mathematical and computation techniques used to generate stochastic representations of different types of structure are similar, regardless of whether the phenomenon is the ambient atmosphere, the auroral-disturbed atmosphere, the nuclear-perturbed atmosphere, or a missile plume. Thus, the SSGM design uses a single structure generation code for all of these environments. The basic procedure generates a gaussian noise image with zero mean and unit variance. This image is then filtered with a two-dimensional power spectral density function representing the stochastic structure, multiplied by a variance image and added to the the deterministically structured image to produce the final result. The time-sequenced deterministically or stochastically computed radiance maps for individual scene elements are then assembled into composite, full field-of-view images in the Composite Image Module. Following Frame Generation, the composite scenes are stored as files in the Digital Scene Library where they can be analyzed and displayed.

When a user's purpose is to generate input data bases for testing sensor or system models or for use in actual hardware simulations, certain features or events in a scene may trigger changes in the definition of subsequent frames. The SSGM contains a Simulation Interface Module which effects the event-driven feedback process when dealing with possible, but temporally unpredictable, events. This module performs a scene diagnostic test to alter subsequent scene generation in accordance with preassigned decision logic. Typically, the feedback loop would only interface with Frame Generation but could require Run-Time Generation to create new Run-Time Library data.

4.0 SSGM PHENOMENOLOGY

The phenomenology consists of quiescent and enhanced natural backgrounds and perturbed backgrounds with imbedded targets and target induced or related events. Endorsed and validated predictive models for these phenomena continue to be developed and refined by government agencies (GL, AL, ASDC, NRL, DNA, NASA, *etc.*) which are also responsible for code verification, validation, and configuration management. NRL rehosts these standard codes, or output data bases generated off-line, within the SSGM architecture and verifies that the composite scenes are accurate renditions as specified by the input scenario.

Table 2 lists candidate codes which are likely to be incorporated in the SSGM architecture. Several of these codes, specifically NORSE for nuclear effects and OSC for hard-body target signatures, are so large or computational intensive that it is impractical to host them within the SSGM. In these cases, the codes are run off-line to generate data bases which are stored in the Element Parameter Library and accessed by more manageable codes. For example, the engagement level nuclear codes PEM and IRSim use NORSE output data bases. Similarly, the SIGNAT interpolation code operates on the GSTS point-source data base for unresolved midcourse objects. Both the code and data base are traceable to the OSC.

The SSGM will integrate, for the first time, strategically relevant phenomenology codes which differ in origin and level of sophistication, into a common architecture. Since SSGM requirements pertain only to the generation of strategic scenes, in some cases it is sufficient to incorporate specific submodules of larger codes (such is the case for midcourse signatures). In other cases the existing codes are currently very research-oriented and require a good deal of hand tailoring to achieve acceptable results. This is the case for certain aspects of missile plume phenomenology. Hence, SPF2 will be used off-line to generate data bases for input into SIRRM which will be an on-line code. A major technical challenge is that the SSGM must simultaneously address configuration management issues relating to SSGM maintenance, augmentation, and traceability in an environment where the fundamental codes themselves are undergoing development.

The SSGM, in general, does not presume to model physical interaction between individual phenomenologies beyond that which is incorporated within the standard

TABLE 2. CANDIDATE SSGM PHENOMENOLOGY MODELS

CATEGORY	OBSERVABLE	CODE/MODEL	DESCRIPTION	RESPONSIBLE AGENCY/ DEVELOPER
TARGET	Missile Plume	SIRRM III	Plume Radiance for 2D/3D Geometries (.7-25 microns,<50 km)	AL/MICOM,GAC,SSI
	Missile Plume	SPF2	Couples Missile Body, Base, & Plume Flowfield (<70 km)	AL/MICOM,PST,Plumtech
	Missile Plume	CHARM 1.2	Flowfield & Plume Radiance (.7-25 microns,>70 km)	AL/LMSC,SSI,AOI,CALSPAN,GAC
	Missile Plume	SPURC	Flowfield & Plume Radiance (.1-.7 microns,>0 km)	AL/GAC,AOI,SSI,PSI
	Plume Transients	SFM	Flowfield & Transients (staging, chuffing, thrust vector control)	AL/SEA,AOI,JAYCOR
	Fuel Release	FRES	Gas Dynamics of Fuel or Oxidizer Vent Cloud combined with Radiance Code	AL/LMSC,Aerospace,PRA
	Target Hard Body	OSC (XV)	Optical Signatures Code	ASDC/TBE
	Target Hard Body	FASTSIG	Exoatmospheric, OSC-like, fast running	ASDC/TBE
	Target Hard Body	SIGNAT	Point Source Data Base & Interpolation	ASDC/TBE
TERRESTRIAL	Hard Earth	GENESSIS	Terrain Scenes	DARPA/PRA
	Cloud	CLDSIM	Cloud Scenes	NRL/PRA
EARTH LIMB	LTE Atmosphere	LOWTRAN(7)	LTE Band Model (Transmission & Radiance)	GL
	LTE Atmosphere	APART(7)	Propogation and Radiative Transport	PRA
	LTE Atmosphere	FASCODE(2)	LTE Line-by-Line (Transmission & Radiance)	GL
	NLTE Atmosphere	FASCODE(2)	NLTE Line-by-Line (Radiance)	GL
	NLTE Limb	HAIRM	NLTE Line-by-Line (Radiance)	GL/Visidyne
	NLTE Limb	ARCHON	Atmospheric Chemistry Code/Database	DNA/MRC
	NLTE Limb	ARC	NLTE (Radiance)	GL
	NLTE Limb	SHARC	NLTE (Radiance)	GL
AURORA	Perturbed Limb	ARCTIC	Aurora (Radiance)	MRC
	Perturbed Limb	AARC	Aurora (Radiance)	GL
NUCLEAR	Perturbed Limb	NORSE	Nuclear Effects Analytic Engineering Application Code (Radiance)	DNA/PRi,MRC
	Perturbed Limb	PEM	Nuclear Effects Engagement Code (Radiance)	DNA/ASDC/PRi
	Perturbed Limb	IRSim	Nuclear Effects Engagement Code (Radiance)	DNA/PRi
SPACE	Celestial IR	CBSD	Zodiacal, Planetary/Interplanetary, Galactic/Extragalactic Point Sources, Diffuse & Structured Background (Radiance)	GL/MRC

models themselves. For example cloud phenomenology, characterized by radiance and transmission maps produced by CLDSIM, is simply overlaid onto terrain phenomenology from GENESSIS during Frame Generation such that there is no current SSGM capability to represent cloud shadows on terrain. However, the SSGM architecture could easily accommodate such a capability if an SDI requirement were to be identified. In fact, some limited interaction of phenomena has been incorporated within the SSGM when believed to be a significant concern to known systems. Such is the case for low-altitude, early-time nuclear fireballs which illuminate terrain and clouds and which may elevate earthlimb, auroral and plume radiances by modifying atmospheric density. Hence, a "dynamic sun" capability has been included during Frame Generation to treat nuclear burst and missile plume irradiance of terrestrial backgrounds, and the Earthlimb module will have access to atmospheric state data from the Nuclear module.

Elsewhere within this volume, the reader will find three papers by members of the SSGM development team which describe SSGM treatments for background and target phenomenologies and for handling spatial and temporal structure. Anding, Mertz and Fleri (PRA) describe terrestrial backgrounds, missile plumes, and midcourse objects in "Background and Target Plume Models of the Strategic Scene Generation Model." Armstrong, McKenzie and Saunders (MRC) discuss the SSGM approach being developed for earthlimb and aurora phenomenologies including treatments for stochastic structure in "Earthlimb and Aurora Background Scene Generation." Blackwell, Stephens, Gomez and Teoh (PRi) describe how structured infrared backgrounds created by nuclear detonations are represented in the SSGM in "Nuclear Backgrounds for SSGM." They also describe how a DNA-produced structure module, which modulates deterministically computed scene elements to produce small scale temporally correlated spatial structure, has been incorporated into the SSGM. For further information on the SSGM program, the reader is referred to Anding *et al.* (1988) and Heckathorn, Anding and Zimmerman (1988). The Baseline SSGM design is described by Anding (1988).

Since the Space Science Division of NRL has a long standing interest in celestial backgrounds, the SSGM implementation of phenomenology models arising out of the development of the Celestial Background Scene Descriptor (CBSD) by the Air Force Geophysics Laboratory will be discussed below. MRC is CBSD prime contractor and SSGM sub-contractor for space backgrounds.

4.1 SSGM SPACE BACKGROUNDS

The Celestial Background Scene Descriptor is being independently developed by the Air Force Geophysics Laboratory to characterize IR celestial backgrounds. The development effort has been described in detail by Price and Kennealy (1989) and will not be repeated here. Major tasks include: 1) the development of a multi-component phenomenological model of the celestial background based on a physical description of the galaxy and the large scale structure of the universe, and 2) the representation of features of the solar system which appear to move against the more distant galactic and extragalactic sources. The moving sources include diffuse zodiacal emission and fine scale features (zodiacal dust bands, asteroidal debris, and cometary dust trails) and discrete components (planets, satellites, and asteroids).

The SSGM SPACE module will incorporate CBSD phenomenological models as modular on-line code which will access CBSD data bases installed in the SSGM Element Parameter Library. Since the CBSD development is simultaneous with the SSGM, the SPACE module will evolve to accommodate CBSD enhancements. Submodules will consist of 1) a galactic and extragalactic point source model (including an algorithm for realistic spatial distribution of point source components), 2) diffuse zodiacal emission (including banded structure), 3) discrete zodiacal components (including ephemerides for planets, satellites, and comet trails and a statistical treatment for asteroids), and 4) a fractal representation of interstellar IR cirrus. Initial capabilities for dealing with galactic and extragalactic point sources (NASA/Ames-JSE SKY model) and zodiacal emission (MRC ZODY model) are currently being installed in the SSGMP.

In the SKY galactic model (Cohen *et al.*, 1989), distinct spectral classes of objects are characterized by individual spatial, spectral and intrinsic brightness distributions (and dispersions) derived from IRAS data. A multi-component model of the galaxy consisting of disk, bulge, spheroid, spiral arm and molecular ring components accounts for galactic structure. The SKY extragalactic model assumes a homogeneous distribution of galaxies and splits the luminosity function into four components. SKY also treats extinction effects due to the general interstellar medium.

The ZODY zodiacal emission model (Cobb, 1989) creates synthetic scenes based on current knowledge of thermal emission from solar system dust. The model uses a data base of volumetric emissivity for astronomical silicates as a function of temperature and wavelength in the IR. This is combined with a model for the spatial distribution and temperature of the dust responsible for the broad zodiacal emission to yield zodiacal scenes. ZODY also treats the three primary dust bands (alpha, beta, gamma) discovered by IRAS above and below the ecliptic plane. The current model includes only blackbody, constant emissivity calculations for these new features but is the first model to combine the diffuse and structured components of the zodiacal emission.

Figures 3 and 4 present recent composite images of IR celestial point source and zodiacal emission based on SKY and ZODY. These images were generated at NRL as a test prior to implementing this capability within the SSGM. SKY creates output files which list the number of stars per magnitude interval within a one square degree area for each (GLONG,GLAT) coordinate pair. Star counts, based on a variable grid matrix of coordinate pairs, were generated using SKY and interpolated using a spline technique. Star brightness was subsequently distributed randomly within one square degree areas and accumulated within individual one arc minute pixels to generate the "stars" seen in the figures which represent a 16° square area near the galactic center. The banded zodiacal structure was generated directly from ZODY for a date which fixed the solar elongation at 135° from frame center. The zodiacal image was rotated from the ecliptic to galactic coordinate system, and geometrically scaled prior to overlaying on the point source image. Since the images presented are not gnomonic projections, there is some residual distortion, but the effect is small in this test because the galactic and ecliptic planes actually cross within the area presented. Radiometric scaling for the images was based on IRAS calibrations and adjusted to represent 1.0 and 0.1 arc minute resolutions (diffraction limits at the 12 μm wavelength for 5-cm and 50-cm aperture optical systems, respectively). Radiance is scaled linearly but is compressed to span the complete dynamic range of the image. When interpreting these figures, the reader should remember two things about the IRIS point source data set which forms the basis of the SKY model: 1) is not homogeneous and will become increasingly incomplete, and therefore biased, at fainter brightness levels and 2) the number of IRAS point sources catalogued near the galactic plane is underestimated due to source confusion.

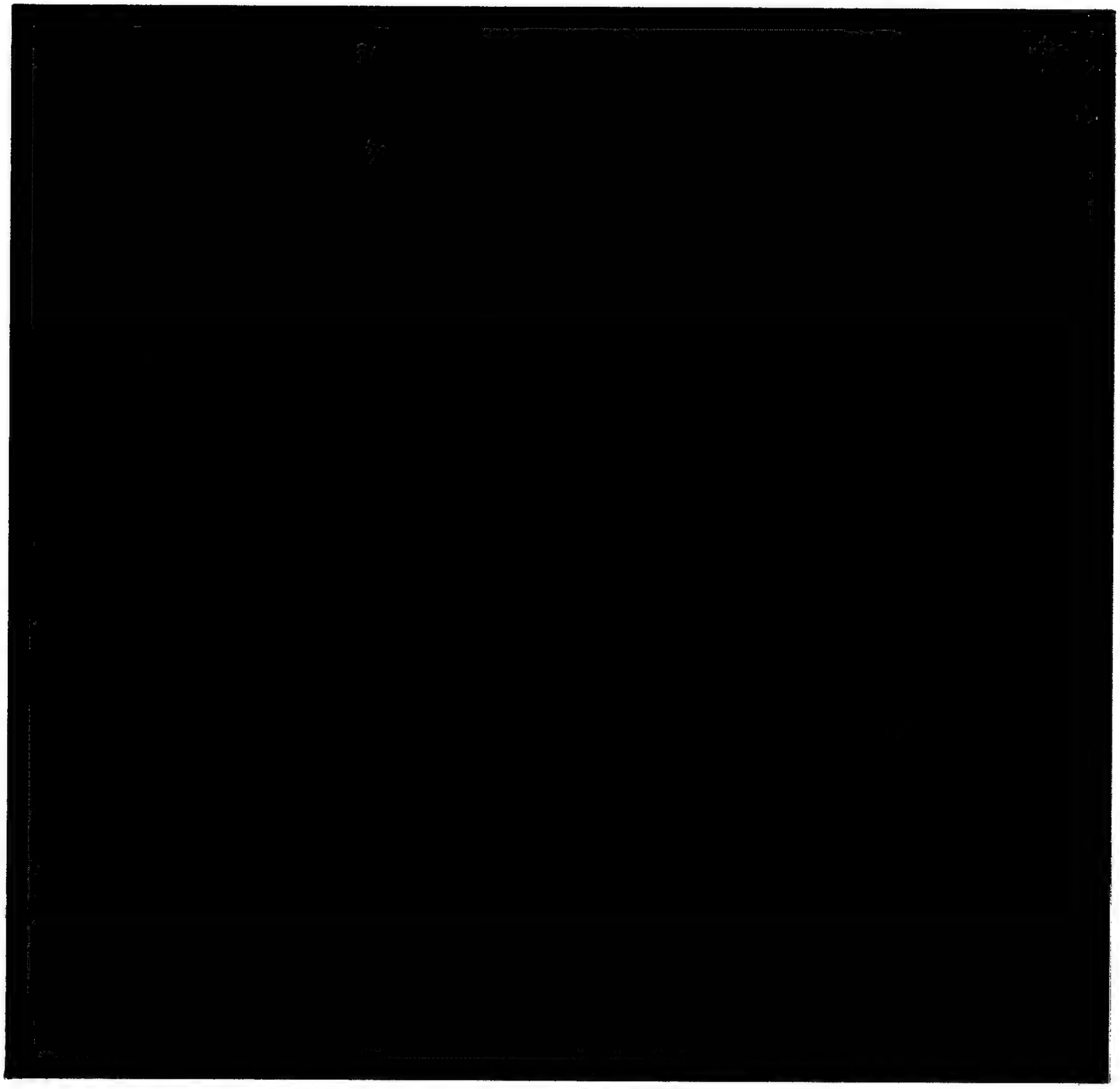


Figure 3. Synthetic IR Celestial Scene in Sagittarius based on SKY and ZODY Models. Wavelength = 12 μm, field-of-view = 16° square, galactic coordinates (GLONG,GLAT) = (6°.4,-4°.0), solar elongation = 135°, resolution = 1'.0 (equivalent to diffraction limited performance of 5-cm aperture optics).

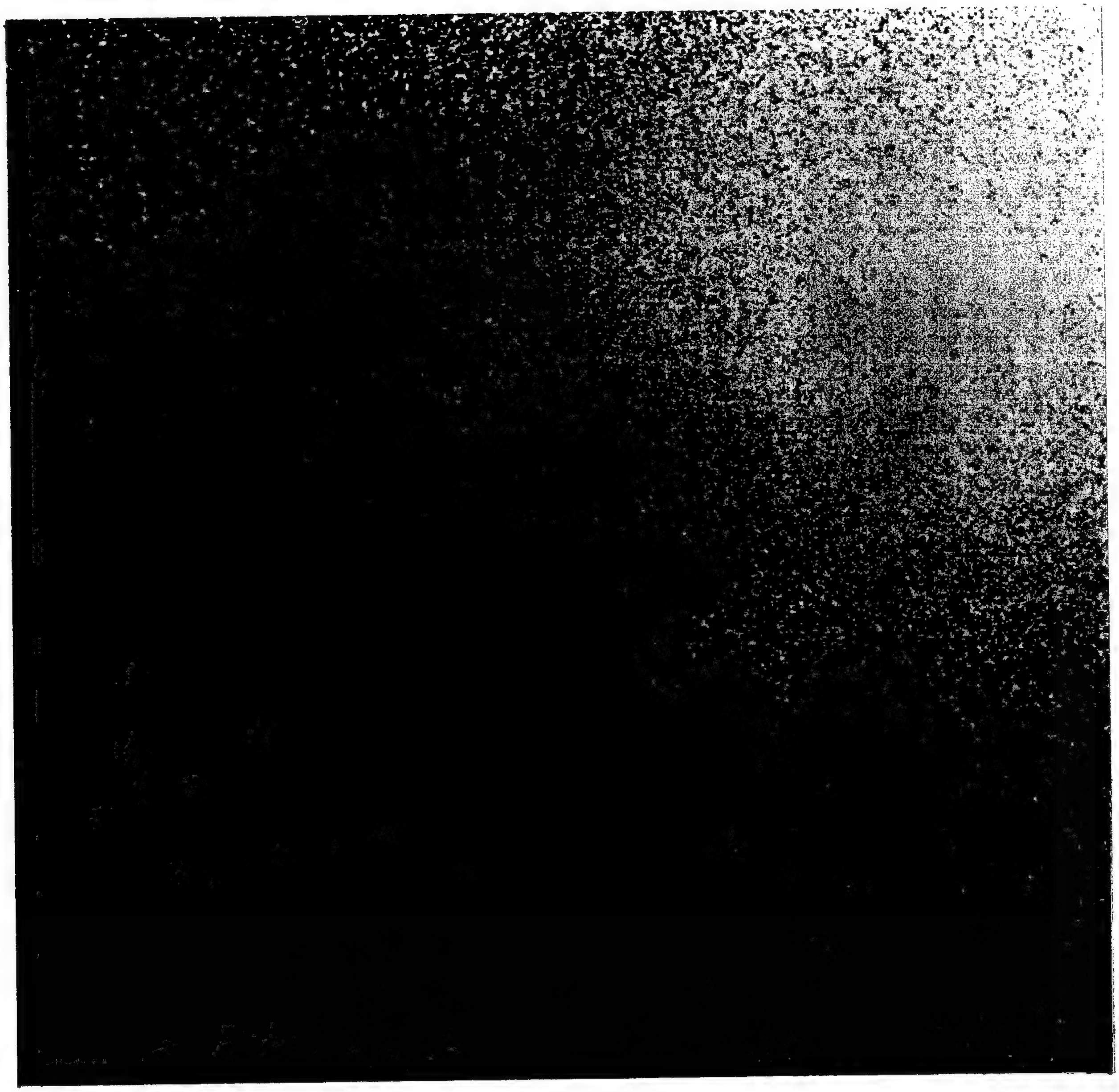


Figure 4. Same composite phenomenology as Figure 3 except the resolution is 0'.1 (equivalent to diffraction limited performance of 50-cm aperture optics at the 12 μm wavelength). Software to randomly distribute point sources and to overlay the structured zodiacal component was developed by NRL. The radiance scales of Figures 3 & 4 are linear but compressed to span the complete dynamic range of the images.

Future CBSD developments involve the application of super-resolution methods to the IRAS data; a fractal representation of spatially complex features such as the interstellar IR cirrus; a comprehensive model for zodiacal emission (including treatments for diffuse and banded structure, comet trails, planets, satellites, and asteroids); and refined multi-component point source models based on a physical description of the galaxy and extragalactic space. The SSGM will incorporate these CBSD enhancements when they become available.

5.0 SUMMARY AND CONCLUSIONS

An evolutionary, multi-phase approach is being taken for SSGM development since the program must provide interim capabilities to meet immediate SDI requirements. The computer architecture has been designed and is being developed to be fully responsive to long term needs; however, the supporting data bases on targets and backgrounds are addressing near term needs and will be limited in the Baseline. The prototype development tested this model architecture, several in-line software modules and representative data bases to create scene elements, the system to manage the various data bases and libraries, and the verification and validation methodology which is based on comparison with empirical data. The data bases will continually expand through support of SDI component initiatives (BSTS, SSTS, GSTS, AMDF, KHILS, etc.).

The primary limitations of the SSGM Baseline, in addition to those pertaining to data bases, are those stemming from the lack of availability of government standard codes for some important phenomenologies. Because of this, the baseline will not include the following treatments:

1. Active laser signatures
2. Target damage effects from directed energy weapons
3. Missile staging signatures and plume persistence
4. Target interaction effects of closely spaced objects
5. Plumes of post-boost vehicles
6. RV deployment signatures

As government standard codes become available for these areas of phenomenology, they will be incorporated.

Another important limitation of the baseline is the speed with which scenes can be generated on conventional parallel processing computers. It is anticipated that for those applications which involve the rapid generation of sequential scenes, the Run-Time Library will be populated by prior executions of the phenomenology submodules. However, for large or complex scenes (those with many objects) the computer time may still be too long to meet the needs of end-to-end simulation systems, particularly real-time hardware-in-the-loop. This limitation will be overcome during the Phase III Operational model development.

REFERENCES

Anding, D. C., "Baseline Design for an Operational Strategic Scene Generation Model", Photon Research Associates document R-131-88, product of NRL contract N00014-87-C-2500, December 1988.

Anding, D. C., Zimmerman, D., Franklin, T., and Heckathorn, H. M., "Strategic Scene Generation Model", Proceedings of IRIS Speciality Group Conference on Targets, Backgrounds and Discrimination, Monterey, CA, February 1988, ERIM Report 199300-20-X(III), p. 241-260, October 1988.

Cobb, M., "User Guide for CBSD ZODY, the CBSD Zodiacal Emission Model", Mission Research Corporation, Nashua, NH, May 1989.

Cohen, M., Walker, R., Wainscot, R., Volk, K., Walker, H., and Schwartz, D., "An Infrared Sky Model Based on the IRAS Point Source Data", Final Report on NASA Contract NAS2-12525(DHC), Jamieson Science and Engineering, Inc., March 1989.

Heckathorn, H., Anding, D. C., and Zimmerman, D., "Strategic Scene Generation Model", Proceedings of the Passive Optical Signatures Symposium, Huntsville, AL, May 1988, Technical Report KE-88—SENSORS-HY-0113.

Price, S. D., and Kennealy, J. P., "The Infrared Celestial Background Scene Descriptor", Vol. 1110 of Proceedings of the Society of Photo-Optical and Instrumentation Engineers, 1989.

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SSGM PROJECT

IRIS -- Targets, Backgrounds & Discrimination

Overview of the Strategic Scene Generation Model (SSGM)

SDIO Technology/Sensor & Interceptor Technology
Scene Generation Phenomenology Program

presented by

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Naval Research Laboratory, Washington, D.C.

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24 January 1990
Naval Postgraduate School
Monterey, CA

Outline of SSGM Overview Presentation

INTRODUCTION	Definition Objectives Requirements Context - SDIO Phenomenology Data Centers, Codes, Users, PSAG
ARCHITECTURE	User Input & Scenario Definition Phenomenology Data Base Generation Scene Generation Event-Driven Simulation Interface
PHENOMENOLOGY	Earth Terrain Clouds Earth Limb & Aurora Nuclear Celestial Targets & Target Related Events
CAPABILITIES, LIMITATIONS, and STATUS	Prototype (SSGMP) Baseline (SSGMB) Operational (SSGMO)
APPLICATIONS	Current User Community & Requirements Distribution

The STRATEGIC SCENE GENERATION MODEL (SSGM) integrates for the first time various phenomenology codes and is accepted as a traceable "standard" for the SDI.

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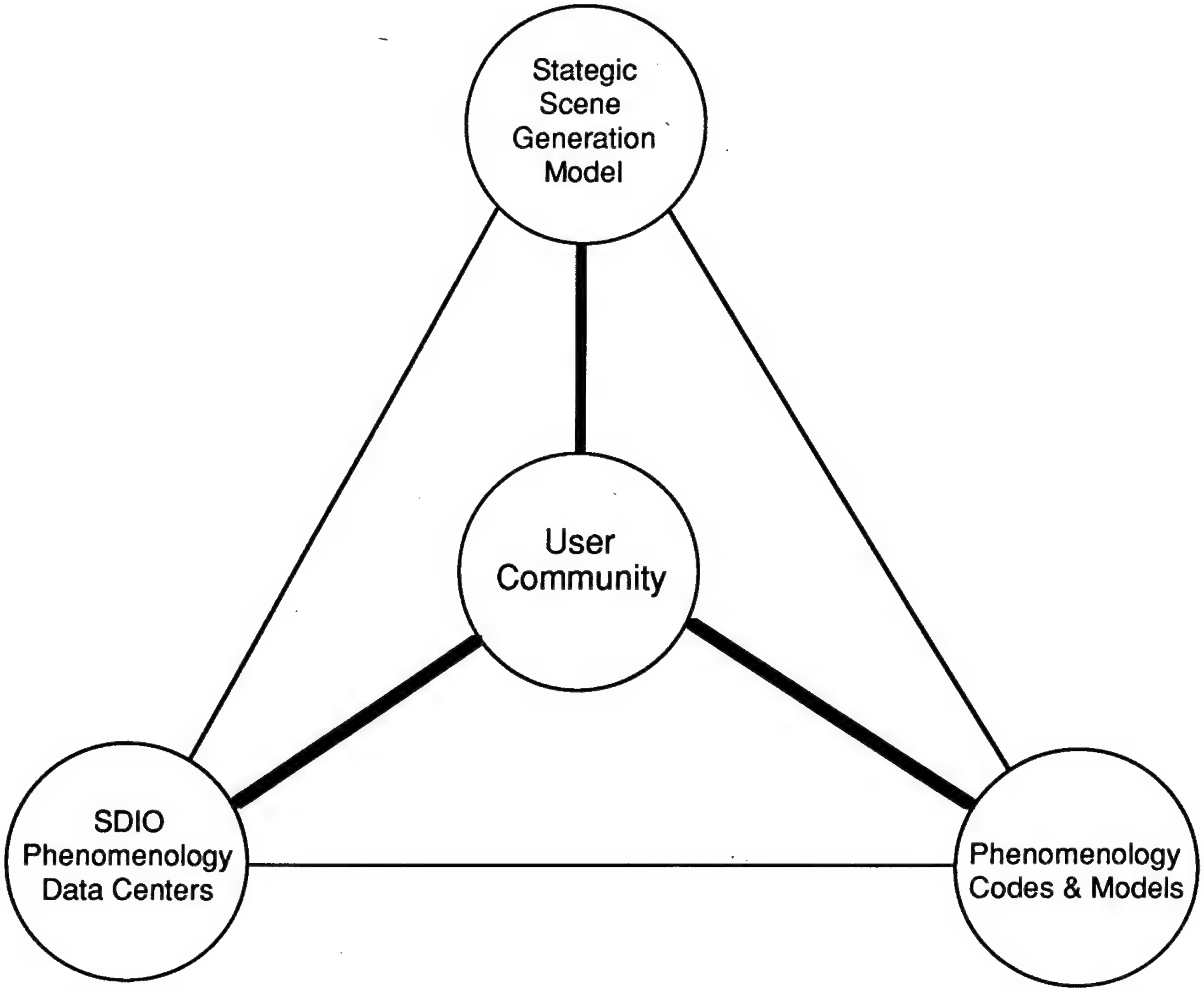
SDIO Data/Model/User Relationship



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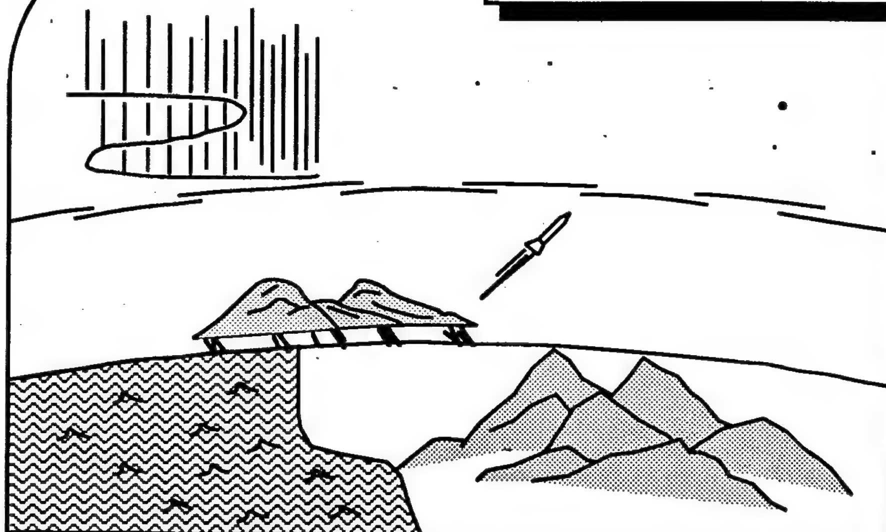

Relationship to SDS

Provide modeled phenomenology of complex, multi-phenomenology scenes for use in design/simulation/test of SDS sensor & system performance

Program Objectives

- Integrate, for the fist time, the various "government-standard" phenomenology codes
- Provide physically valid scenes, and/or the capability to generate them, thereby serving as a standard for testing different SDI concepts and designs
- Scenes to be constrained only by the limitations in the physical models and empirical data bases

Technical Challenges

- Incorporate phenomenology codes which differ in origin/purpose/sophistication
- Verification & Validation of composite scenes
- Computational burden for creating/resampling image data bases in reasonable times
- Requirements for event-driven scenarios, interaction of scene elements, active illumination
- Configuration Management issues relating to SSGM maintenance, augmentation, traceability as fundamental phenomenology codes evolve

Strategic Scene Generation Model (SSGM)

Definition

Computerized methodology founded on state-of-science knowledge, empirical data bases & phenomenological models to generate LOS radiometrics, 2-D radiance binary images, time-sequenced dynamic scenes & observables data bases for SDI applications

Requirements

Phenomenology: targets and target related events, natural and nuclear backgrounds

Scenarios: relevant vehicle types and trajectories (launch, midcourse, reentry)

Dimensions: relevant spatial, temporal and spectral sampling regimes

Geometry: all sensor/scene/target locations and time-history sequences

Connectivity: event-driven, both passive and active (illuminated) signatures, limited interaction of phenomenologies

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Parties Involved in SSGM Development

ORGANIZATION	ACRONYM	SSGM ROLE
Naval Research Laboratory Space Science Division	NRL	Program Management
Sensor & Interceptor Technology	SDIO/TNS	Sponsor
Phenomenology Steering and Analysis Group	PSAG	Monitor Development thru PSAG User Product Subgroup
Photon Research Associates San Diego, CA	PRA	Prime Contractor Software Architecture, Missile Plumes, Terrestrial Backgrounds
Mission Research Corp. Nashua, NH	MRC	Subcontractor Earthlimb, Aurora & Celestial
Physical Research, Inc. Huntsville, AL	PRi	Subcontractor Nuclear, Stochastic Structure
The Analytic Sciences Corp. Reading, MA	TASC	Subcontractor Data Base Management System
Teledyne Brown Engineering Huntsville, AL	TBE	Subcontractor Midcourse Object Signatures
Image Data Corp. Pasadena, CA	IDC	Subcontractor Software Optimization

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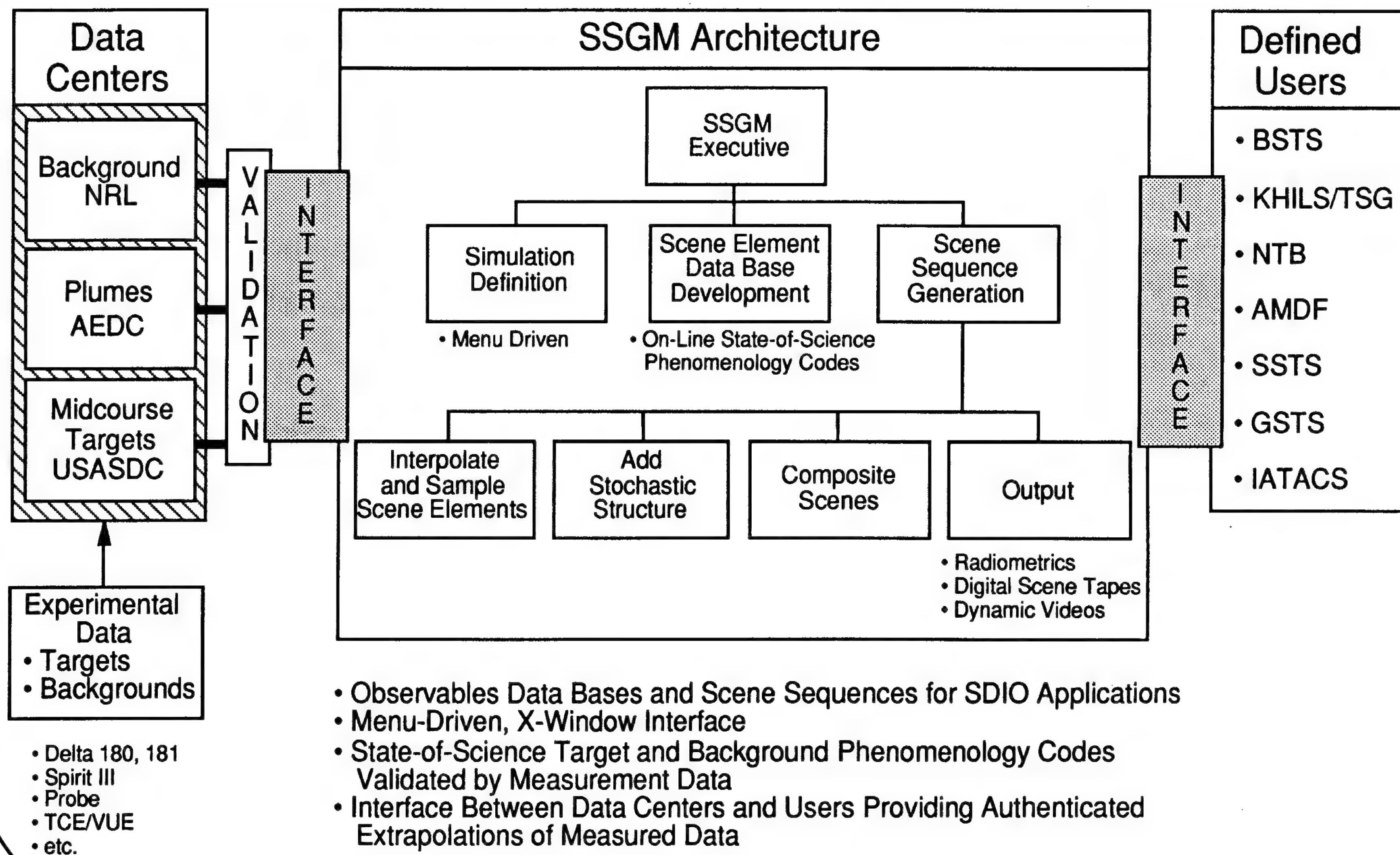
SDIO Phenomenology DataCenters--SSGM--Users Relationship



- Observables Data Bases and Scene Sequences for SDIO Applications
- Menu-Driven, X-Window Interface
- State-of-Science Target and Background Phenomenology Codes Validated by Measurement Data
- Interface Between Data Centers and Users Providing Authenticated Extrapolations of Measured Data

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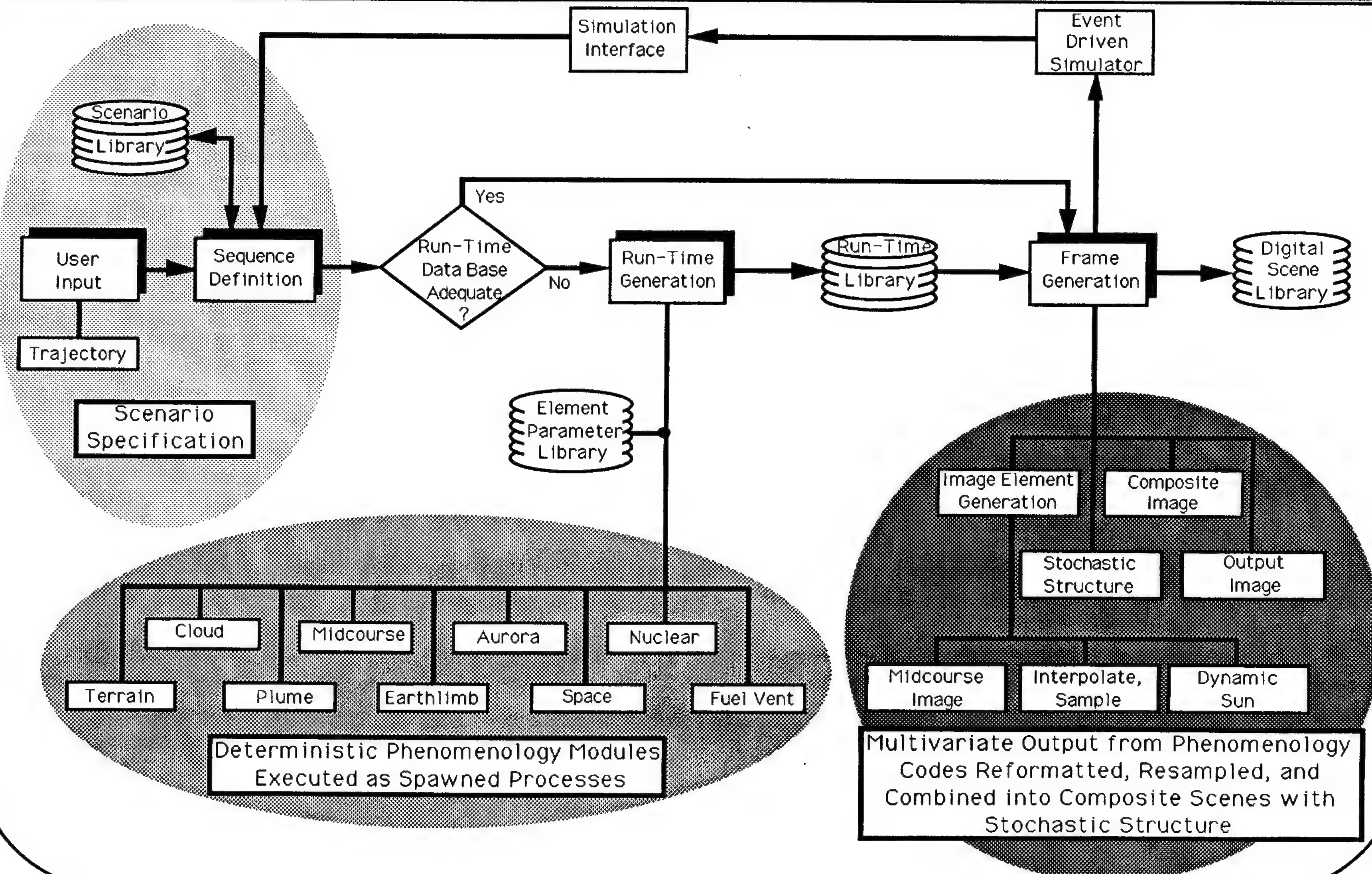
Baseline SSGM Functional Flow



SSGM Prototype (SSGMP) Characteristics

- Implementation
  - -- on-line codes and supporting input data bases for background phenomenologies below the troposphere
  - -- scene generation software modules to resample and interpolate, add stochastic structure to the results of deterministic models, synthesize scene elements into composite scenes and time sequences, and output final results
  - -- DBMS software for management of libraries (Scenario, Element, Run-Time, Scene)
  - -- FORTRAN 77 exclusively

- Additional data bases computed from off-line government standard codes for quiescent and perturbed natural backgrounds (earthlimb, aurora, and celestial), man-made nuclear backgrounds, and targets or target related persistance phenomena (missile plumes, fuel vents, and mid-course objects)

- Technical Documentation
  - -- User's Guide
  - -- Technical Reference Manual
  - -- Software Reference Manual

SSGM Baseline (SSGMB) Characteristics

- Baseline SSGM evolves from SSGMP which is maintained and refined
- Pre-computed data bases replaced with on-line phenomenology codes and supporting input data bases phased to SDIO requirements and priorities
- Initial development of a spanning set of comprehensive input data bases meeting many anticipated SDIO scene generation requirements for a variety of engagement scenarios
- Implements support of event-driven simulations where the requirements for time-sequenced frames evolve from several possible but unpredictable events
- Supports limited interaction of selected phenomenologies including terrain and cloud illumination by nuclear and missile plume radiation, and nuclear heave effects on earthlimb and auroral radiance
- Improves user interface and computational efficiency
  - -- FORTRAN 77 and C, UNIX Operating System
  - -- menus viewed/altered via X-windows
  - -- on-line trajectory computation for targets, sensors & background phenomenology
  - -- software coded/optimized for vectorizing/parallelizing compilers

Phenomenology Models (Natural Elements)

CATEGORY	OBSERVABLE	CODE/MODEL	DESCRIPTION	RESPONSIBLE AGENCY/ DEVELOPER
TERRESTRIAL	Hard Earth	GENESSIS	Terrain Scenes	DARPA/PRA
	Cloud	CLDSIM	Cloud Scenes	NRL/PRA
EARTH LIMB	LTE Atmosphere	LOWTRAN(7)	LTE Band Model (Transmission & Radiance)	GL
	LTE Atmosphere	APART(7)	Propogation and Radiative Transport	PRA
	LTE Atmosphere	FASCODE(2)	LTE Line-by-Line (Transmission & Radiance)	GL
	NLTE Atmosphere	FASCODE(2)	NLTE Line-by-Line (Radiance)	GL
	NLTE Limb	HAIRM	NLTE Line-by-Line (Radiance)	GL/Visidyne
	NLTE Limb	ARCHON	Atmospheric Chemistry Code/Database	DNA/MRC
	NLTE Limb	ARC	NLTE (Radiance)	GL
	NLTE Limb	SHARC	NLTE (Radiance)	GL
AURORA	Perturbed Limb	ARCTIC	Aurora (Radiance)	MRC
	Perturbed Limb	AARC	Aurora (Radiance)	GL
SPACE	Celestial IR	CBSD	Zodiacal, Planetary/Interplanetary, Galactic/Extragalactic Point Sources, Diffuse & Structured Background (Radiance)	GL/MRC

Phenomenology Models (Man-made Elements)

CATEGORY	OBSERVABLE	CODE/MODEL	DESCRIPTION	RESPONSIBLE AGENCY/ DEVELOPER
TARGET	Missile Plume	SIRRM III	Plume Radiance for 2D/3D Geometries (.7-25 microns,<50 km)	AL/MICOM,GAC,SSI
	Missile Plume	SPF2	Couples Missile Body, Base, & Plume Flowfield (<70 km)	AL/MICOM,PST,Plumtech
	Missile Plume	CHARM 1.2	Flowfield & Plume Radiance (.7-25 microns,>70 km)	AL/LMSC,SSI,AOI, CALSPAN,GAC
	Missile Plume	SPURC	Flowfield & Plume Radiance (.1-.7 microns,>0 km)	AL/GAC,AOI,SSI,PSI
	Plume Transients	SFM	Flowfield & Transients (staging, chuffing, thrust vector control)	AL/SEA,AOI,JAYCOR
	Fuel Release	FRES	Gas Dynamics of Fuel or Oxidizer Vent Cloud combined with Radiance Code	AL/LMSC,Aerospace,PRA
	Target Hard Body	OSC (XV)	Optical Signatures Code	ASDC/TBE
	Target Hard Body	FASTSIG	Exoatmospheric, OSC-like, fast running	ASDC/TBE
	Target Hard Body	SIGNAT	Point Source Data Base & Interpolation	ASDC/TBE
NUCLEAR	Perturbed Limb	NORSE	Nuclear Effects Analytic Engineering Application Code (Radiance)	DNA/PRi,MRC
	Perturbed Limb	PEM	Nuclear Effects Engagement Code (Radiance)	DNA/ASDC/PRi
	Perturbed Limb	IRSim	Nuclear Effects Engagement Code (Radiance)	DNA/PRi

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SSGM Papers at this IRIS/TBD Meeting

Authors/Affiliation	Title/Content/Codes
Heckathorn & Anding Naval Research Laboratory (NRL) & Photon Research Associates (PRA) -- PRESENTATION --	"Overview of the Strategic Scene Generation Model (SSGM)" SSGM Program Description, Requirements, Architecture, Phenomenology, Celestial Backgrounds Codes: CBSD, SKY, ZODY
Anding, Mertz & Fleri Photon Research Associates (PRA) -- POSTER --	"Background & Target Plume Models of the Strategic Scene Generation Model" Terrestrial Background (Terrain & Cloud), Missile Plumes, Midcourse Objects, and SSGM Frame Generation Software Codes: GENESSIS, CLDSIM, APART, SPF2, SIRRM, CHARM, OSC, SIGNAT
Armstrong, McKenzie & Saunders Mission Research Corporation (MRC) -- POSTER --	"Earthlimb and Aurora Background Scene Generation" Natural LTE & NLTE Atmospheric Radiance, Deterministic/Stochastic Structure, and SSGM Earthlimb/Aurora Submodules Codes: LOWTRAN, APART, HAIRM, ARCHON, SHARC, NLTE, ARCTIC
Blackwell, Stephens, Gomez & Teoh Physical Research, Inc. (PRi) -- POSTER --	"Nuclear Backgrounds for SSGM" IR Nuclear Backgrounds, Temporally Correlated Stochastic Structure and SSGM Nuclear Submodule & Data Bases Codes: NORSE, PEM, IRSim, STRCTR

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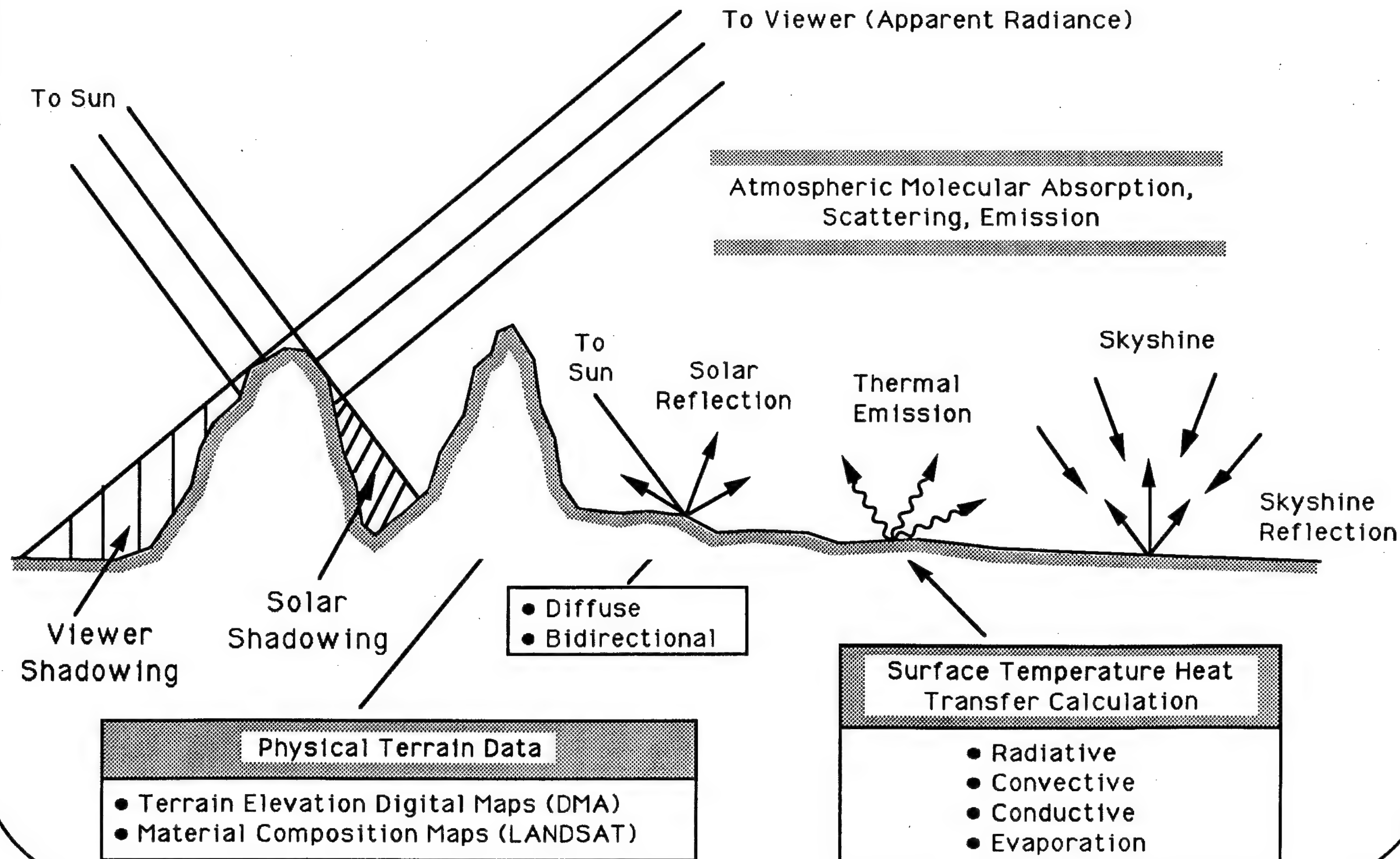
GENESSIS: Earth Terrain Scene Model



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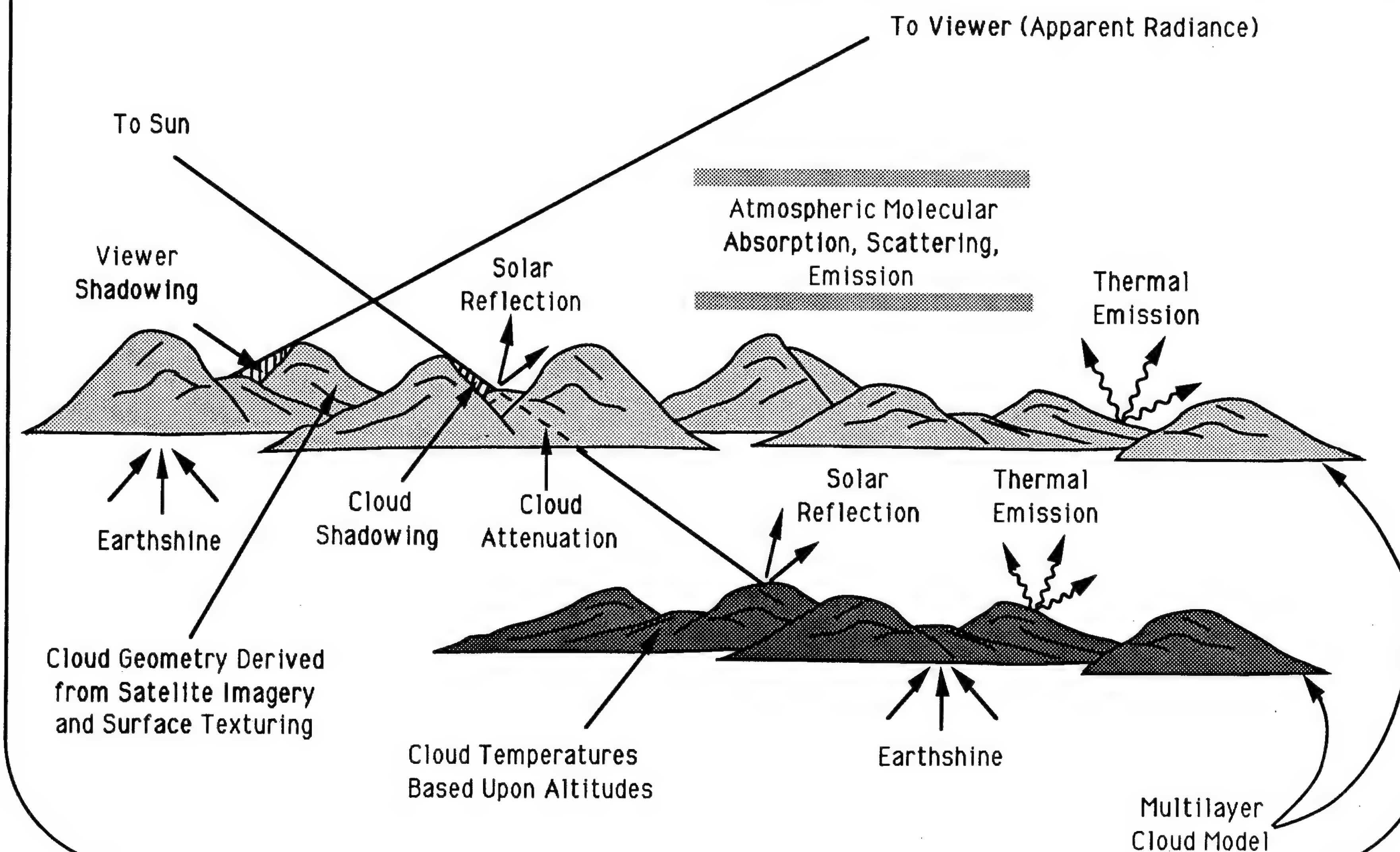
CLDSIM: Atmospheric Cloud Scene Model



Trial Generation of Celestial Scenes at NRL

PHENOMENOLOGY MODELS:

- NASA/AMES-JSE IR Point Source Model (**SKY**)
- GL/CBSD-MRC Zodiacal Emission Model (**ZODY**)

NRL MODIFICATIONS, ADDITIONAL SOFTWARE & IMAGE PROCESSING:

- SKY modified to yield number of stars per magnitude interval within one square degree area for each (GLONG,GLAT) coordinate pair
- Program **STARMAP** created
  -- performs spline interpolation on star counts for a sparcely sampled matrix of coordinates
  -- randomly distribute stars (accumulates brightness in IFOV pixels) within one square degree areas
- Interactive image processing for Radiometric & Geometric Scaling and Rotation & Addition of Zodiacal and Point Source Images

REQUIRED INPUTS	EXAMPLE VALUES
Line-of-Sight (GLONG,GLAT)	6.4,-4.0 (SAGITTARIUS)
Image Size (FOV)	16x16 degrees
Angular Resolution (IFOV)	1 arc minute
Solar Elongation and Date	135 degrees, 8 August
Wavelength	12 µm

Current SSGM User Community

PROGRAM	AGENCY	SSGM APPLICATION
BSTS	SD	Standard fixed-frame SWIR & MWIR scenes for hardware demonstrations, digital simulations, and evaluation of system performance predictions (SN)
SSTS	SD	Midcourse LWIR scenes to support system demonstration and validation methodology (SN)
GSTS	ASDC	Requirements similar to SSTS but with target discrimination (SN)
KHILS	AFATL	SSGM software to meet scene data base generation requirements for the Target Scene Generator (KE)
IATACS	WL	Dynamic scenes for the Integrated Acquisition, Tracking and Aimpoint Control System (DE)
AMDF	RADC	SSGM software to generate scene data bases for the Attack Management Development Facility (DE)
NTB	ESD	SSGM software to support NTF system evaluations and simulations (NTB)

SN = Surveillance Sensor, KE = Kinetic Energy, DE = Directed Energy

Long-Term SSGM Development & Implementation Schedule

	Completion Date	Major Deliverables	SSGM Characteristics & Capabilities
Phase I (SSGMP)	2/89	• Design/Build Prototype SSGM • Design Baseline SSGM • Documentation & Manuals	• Background Phenomenologies below Troposphere On-Line • 2.7, 4.3, 10-14 μm Bands • Fortran-77, UNIX & VMS
Phase II (SSGMB)	9/92	• Maintain Prototype SSGM • Code/Build Baseline SSGM • Develop/Update Data Bases • Optimize Code for Parallel Processing • Implement Configuration Management • Verification & Validation • Documentation & Manuals	• Fully Functional SSGM • All Phenomenologies On-Line • Event-Driven Capability • Dynamic Sun & Nuclear Heave • Limited Set of Data Bases • X-Window User Interface • Fortran-77, "C", UNIX
Phase III (SSGMO)	9/94	• Maintain Baseline SSGM • Build Operational SSGM • Specialized Hardware • Independent Verification and Validation Contract	• Near Real-Time Capability • Spanning Set of Data Bases • Updated Phenomenology Codes
Phase IV (SSGM)	----	• Maintenance Phase • Configuration Management	• Updated Phenomenology Codes • Expanded Set of Data Bases

Background and Target Plume Models of the Strategic Scene Generation Model*

January 1990

David C. Anding
Frederick C. Mertz
Dr. Edward Fleri

Photon Research Associates, Inc.
San Diego, CA 92121

ABSTRACT

The Strategic Scene Generation Model (SSGM) generates representations of terrain and cloud background images using government standard codes: Generic Scene Simulation Software (GENESSIS) for terrain and Cloud Simulation (CLDSIM) for clouds. The SSGM generates image representations of the plumes of boosting missiles and midcourse hardbody post-boost vehicles, reentry vehicles, and decoys. Plumes are represented using the Standard Plume Flowfield - Version 2 (SPF2) and the Standard Infrared Radiance Model (SIRRM) for altitudes less than 50 km, and the Composite High Altitude Radiance Model (CHARM) 1.2 for altitudes above 50 km. Midcourse vehicles are represented using the BIDIRC software of the Optical Signatures Code (OSC). The plume and midcourse images are overlayed upon background images to generate composite output scenes.

This paper presents the automated methodology by which the SSGM interfaces with the user to invoke the execution of the requisite computer codes, formats code output for input to the scene generation process, interpolates and resamples code output to form images, and overlays individual images into composite scenes. This paper also presents overviews of the GENESSIS and CLDSIM codes, including discussions of the procedures used to treat the various radiation mechanisms. Example outputs from GENESSIS and CLDSIM are presented in addition to plume images as they appear when composited with the background images.

1.0 INTRODUCTION

This paper is an amendment to a companion paper entitled "Overview of the Strategic Scene Generation Model (SSGM)" by H. Heckathorn, Naval Research Laboratory, Washington, DC; and D. Anding, Photon Research Associates, San Diego, CA. It provides an expanded description of the image generation process for terrain and cloud backgrounds and for plume and midcourse targets.

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* This work is being performed for the Space Science Division of the Naval Research Laboratory under Contract N00014-89-C-2283 with support from the Sensors Directorate of the Strategic Defense Initiative Office.

The SSGM is a FORTRAN 77 ANSI standard computer code which calculates pixel images of backgrounds, targets, and composite images as either single images or image sequences. Each image pixel is represented as line-of-sight apparent radiance incident on a sensor aperture. Each image contains all radiation sources known to be important to SDI surveillance applications (although each are treated at different levels of approximation) and is a result of all relevant emissive and scattering processes.

The SSGM is in development by the Naval Research Laboratory under the support of the Strategic Defense Initiative Office with planned completion in September 1992. The prime contractor is Photon Research Associates, Inc. Subcontractors are Image Data Corporation, Mission Research Corporation, Physical Research, Inc., The Analytic Science Corporation, and Teledyne Brown Engineering. When complete the SSGM will be available for limited distribution. According to its present design it will be transportable to any virtual memory computer with 8 MBytes of RAM, a UNIX operating system, and an X-window compatibility.

2.0 SSGM ARCHITECTURE

The architecture of the SSGM is shown in Figure 1. The Executive controls four modules, which are executed in sequence. These are: User Input (USRINP), Sequence Definition (SEQDEF), Run-Time Generation (RNTMGN), and Frame Generation (FRMGEN). USRINP outputs are stored in the Scenario Library for recall and display. SEQDEF outputs are stored in the Scenario Library for recall and USRINP use and display. They are also stored in files for input to RNTMGN and FRMGEN. RNTMGN outputs are stored in the Run-Time Library for FRMGEN use and image display by USRINP. FRMGEN accesses the Run-Time Library data bases and computes output images.

2.1 USRINP FUNCTIONS

The USRINP module is a separate executable and is actually composed of two modules: USRINP(X) and USRINP(F). The (X) module provides an X-window menu input capability and the (F) module allows for input through predefined files. Only the X-window capability will be discussed further in this paper.

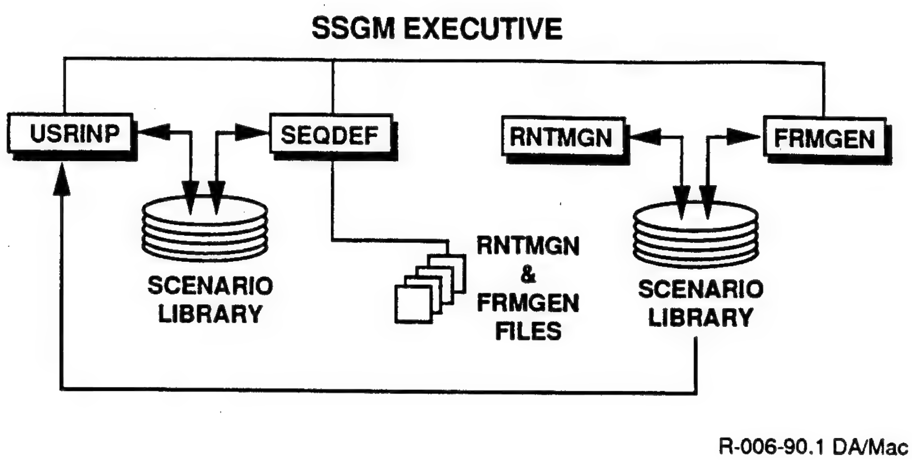

FIGURE 1. SSGM ARCHITECTURE.

The X-window USRINP capability is being developed as transportable software for implementation on any UNIX, X-window compatible workstation. It is also being developed as a user-interactive system on a Silicon Graphics Incorporated (SGI) workstation.

The X-window menu inputs are in the final stages of design and therefore, cannot be definitized herein. Their content will include the following:

A. Sensor
   - o Trajectory Input Parameters
   - o Stare Location (Latitude, Longitude, Altitude)
   - o Scan Option (Includes Target Track)
   - o Waveband
   - o IFOV, # Rows, # Columns
   - o Begin Time, End Time, Framing Interval

B. Background
   - o Scene ID
   - o Location (Latitude, Longitude)
   - o Model Atmosphere

C. Target

- o Target ID
- o Trajectory Input Parameters (Option)
- o Trajectory Launch Location
- o Trajectory Azimuth
- o Time of Launch

The USRINP module will contain an on-line sensor trajectory calculation, for either orbits or ballistic probes. The inputs to these computations are provided through the X-window menu. The same trajectory algorithms will also be available as an option to compute ballistic target trajectories. Normally, target trajectories are precomputed (in accordance with threat information) and stored in a target file for recall through the target ID menu input.

The number of required menu inputs is relatively small since the largest amount of inputs come from pre-established files associated with either the scene ID or the target ID. The details of these files are in final design.

The SGI workstation interface is being developed as a user-interactive scenario construction process. This is needed to construct the specific sensor-target time-sequenced engagement geometries without having to perform complicated computations off-line. (The actual computations are performed by SEQDEF and are discussed in Section 2.2.) Key parameter values which will be set during this process are:

1. Placement of the sensor line-of-sight (LOS) direction and the field-of-view (FOV) size (through specification of the IFOV, # rows, # columns).

2. Placement of the background scene location.

3. Placement of the target launch position, trajectory azimuth and time of launch.

Control of these variables allows the user to manipulate a limited set of background scene and target data bases relative to a variable sensor position,

LOS direction and FOV size to achieve any designed sensor-target engagement scenario.

2.2 SEQDEF FUNCTIONS

The SEQDEF module performs two major functions: the on-line computation of the sensor-target engagement geometries (used by USRINP in the user-interactive scenario construction process, and used by FRMGEN to compute output scenes) and the computation of the data needed by RNTMGN to develop the data base needed by FRMGEN to construct the output scenes. Specifically, SEQDEF computes:

1. Sensor position and LOS direction versus time.

2. Target position and orientation versus time.

3. Geometric mapping of sensor FOV pixels onto background elements and target elements.

4. All geometric data (e.g., interpolation and resampling parameter values) needed by FRMGEN to compute the output scenes.

2.3 RNTMGN FUNCTIONS

The RNTMGN module consists of independent executable codes for each background and target scene component. Relative to the subject matter of this paper, this includes those for terrain, cloud, missile plumes, and midcourse target elements. These codes generate the run-time data bases needed to support frame generation for the specific scenario developed by the user input module. These data bases are generated through multiple phenomenology code executions invoked by RNTMGN as "spawned processes". Through this process these codes remain as stand-alone executables and can be updated and/or modified without affecting the SSGM itself. The output of these codes are formatted and installed into the Run-Time Library for use by FRMGEN. In doing this the Run-Time Library data bases come under the control of the SSGM data base management system.

2.4 FRMGEN FUNCTIONS

The FRMGEN modules, in accordance with the frame generation requirements set up by SEQDEF, accesses the run-time data bases and computes composite output scenes. Specifically, FOV images for terrain, cloud, plume, and midcourse (called image chips) are computed separately. They are computed by interpolating and/or sampling the run-time data bases. The image chips are then placed into composite scenes by overlaying the image chips, accounting for the effects of nearer field chips absorbing all (blockage) or part of (transmission) the radiation from farfield chips.

3.0 METHODOLOGY FOR TERRAIN, CLOUD, AND TARGET REPRESENTATIONS

The procedures used by the SSGM to construct the image chips for terrain, cloud, missile plumes, and midcourse objects are discussed separately in Sections 3-1 through 3-4.

3.1 TERRAIN

Terrain image chips are constructed during frame generation by sampling a run-time data base generated by GENESSIS. Figure 2 shows a schematic of this process. The terrain scene to be represented is defined on a plane tangent to the earth's surface at the latitude and longitude specified by the user. This "flat earth" approximation allows the treatment of atmospheric effects (transmission, emission) to be constant over the spatial extent of scene (reducing computer time), i.e., the change in the atmospheric exit angle for the viewer-solar rays due to earth surface curvature is neglected. This approximation is valid because the terrain scene sizes are small (less than 40 km). The specific GENESSIS data base (see Section 4.0) is defined relative to this plane such that the rows lie east-west and the columns north-south.

The GENESSIS code is executed to produce LOS apparent radiance at the sensor aperture for each point along the N rows and M columns of the uniformly spaced grid of the GENESSIS input scene data base. For a fixed position sensor (e.g., in geosynchronous orbit) only one data base is generated. For a moving sensor, multiple data bases are generated by GENESSIS corresponding to

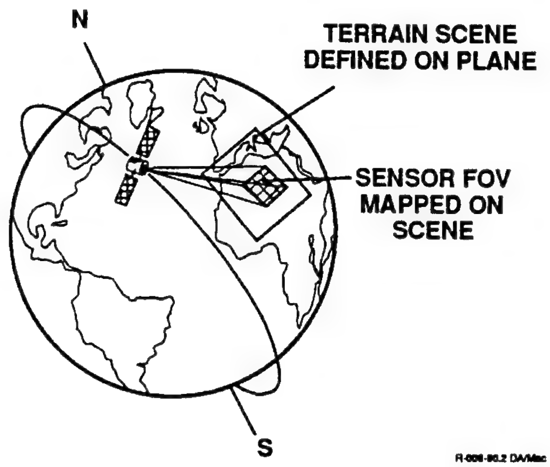

FIGURE 2. SCHEMATIC OF THE TERRAIN IMAGE CHIP GENERATION PROCESS.

a uniform discrete sampling of the continuously changing sensor views of the terrain scene. Each computed data base is formatted and stored in the Run-Time Library with its associated LOS elevation angle.

During frame generation, the sensor FOV pixels are mapped onto the target plane (for each output frame). The FOV image chip is computed by first interpolating LOS radiance (for each run-time data base point) for the sensor FOV elevation angle and then by sampling the run-time data base (for each sensor FOV pixel) using one of three user-specified options:

1. Nearest Neighbor
2. Bilinear Interpolation
3. Cubic Convolution

Each option yields an increasingly accurate result at the penalty of increased computer time. The outputs are the desired sensor-perceived image chips.

3.2 CLOUD

Cloud image chips are generated by a process very similar to that for terrain but with three differences. First, the reference altitude of the

cloud data base is defined on the earth's surface rather than on a plane (see Figure 3). This is required because the cloud data bases are larger and the flat-earth approximation is no longer valid. Second, the LOS apparent radiance for each point in the cloud data base is calculated by CLDSIM. Third, CLDSIM also computes the cloud transmission for each LOS. This is used when the composite scenes are generated to attenuate those scene elements below the clouds (e.g., plumes, terrain). Other than these three differences all aspects of the terrain and cloud processes are identical. This includes the fixed sensor and moving sensor treatment, the run-time data base formats, and the frame generation interpolation and sampling procedures.

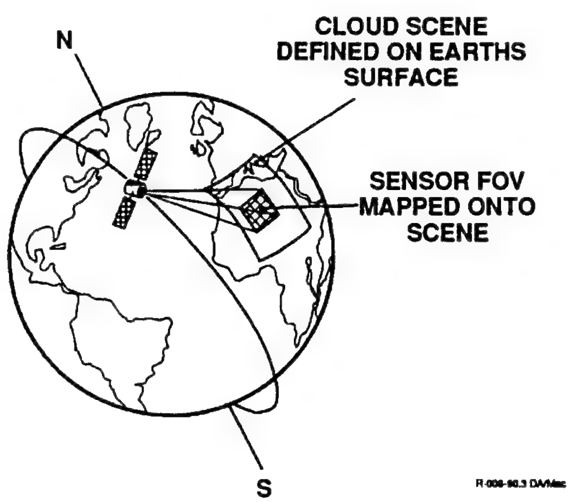

FIGURE 3. SCHEMATIC OF THE CLOUD IMAGE CHIP GENERATION PROCESS.

3.3 PLUME

The plume image chip methodology uses a run-time data base which is target-specific but completely independent of the sensor viewing parameters. These are only imposed during the frame generation process.

For plumes, the target trajectories are user-specified and reside in a file prior to SSGM execution with a given target ID. The trajectory data includes position, velocity, and orientation versus time from launch to upper stage burnout, as well as the staging times.

Target LOS radiance is computed at discrete altitudes from launch to upper stage burnout and at discrete aspects from nose to tail. These are computed using SPF2 and SIRRM below 50 km altitude, and CHARM above 50 km. Between 50 and 70 km only the intrinsic core of the plume is represented. Below 50 km a plume transmission data base is also generated (which is used to attenuate the SIRRM LOS radiance values) which is given as a function of altitude and atmospheric exit angle.

Plume LOS radiance is calculated over the extent of the plume sampled on a variable-spatial-grid as shown in Figure 4. For each altitude and aspect a variable-spatial-grid LOS radiance is generated and stored in the run-time data base. Each data base element contains the same number of LOS points to simplify the interpolation and resampling process.

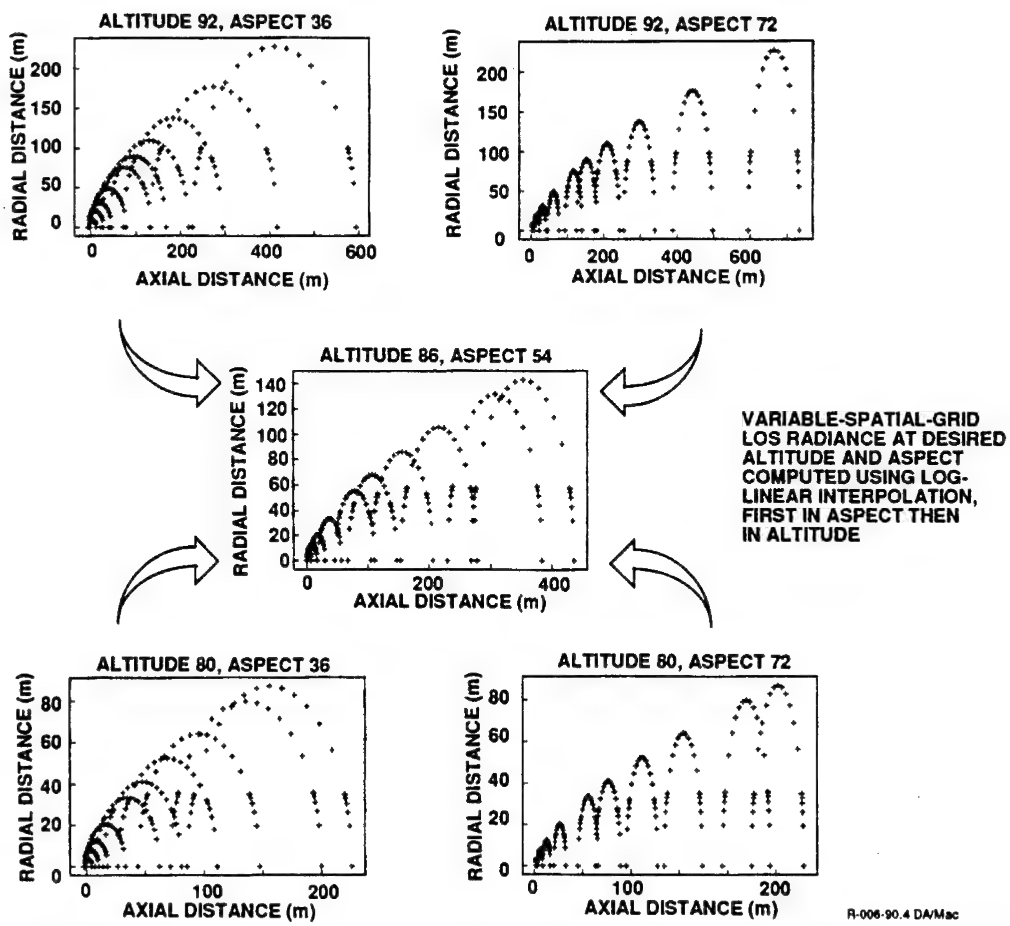

FIGURE 4. PLUME LOS RADIANCE RUN-TIME DATA BASE AND INTERPOLATION PROCESS.

During frame generation, each output plume image chip is computed by first interpolating the bounding altitude-aspect data bases to generate a LOS variable-spatial-grid map at the required altitude and aspect (see Figure 4) and then converting the variable-spatial-grid map to a pixel image chip using a CHARM-specific spatial sampling algorithm. Figure 5 is an example plume image generated through the interpolation and sampling process. The spatial resolution at which this image is generated is user-specified but defaulted to 10 meters. It is down-sampled to the sensor output resolution during scene compositing.

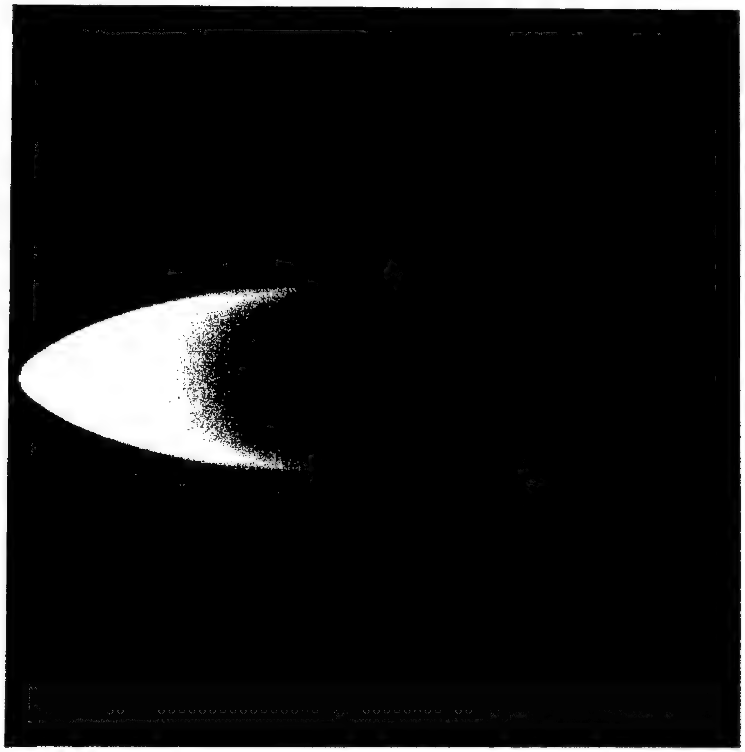

FIGURE 5. PLUME IMAGE CHIP COMPUTED BY CHARM SPATIAL SAMPLING ALGORITHM.

3.4 MIDCOURSE

Midcourse objects represented by the SSGM are re-entry vehicles and their buses, and decoys. (Post-boost vehicle (PBV) plumes will not be represented in the baseline SSGM until a government standard PBV plume model is developed. When available, the procedure for PBV plume image chip computation will be the same as for boosting plumes.) All are opaque objects whose signatures are comprised of reflected solar and earthshine radiation, and emitted radiation.

Midcourse object trajectories are user-specified and reside in a file prior to SSGM execution with a given target ID. The trajectory data includes position and orientation versus time.

Signatures are computed using one of two options: image or point source.

3.4.1 IMAGE OPTION

The image option computes LOS radiance for each pixel of an image chip computed by the OSC subroutine BIDIRC, which will exist in the SSGM as a subroutine of the FRMGEN module. BIDIRC will access input files from the Run-Time Library, prepared by other submodules of the OSC. These files include multifaceted geometry, surface optical properties, facet temperatures, trajectory data, and earthshine illumination.

The Run-Time Library data base will be generated with OSC on-line stand-alone software, executed as a "spawned process". The following OSC programs are utilized:

EXOENV - Calculates solar, albedo, and earthshine radiation environment for input to EXOHEAT3 (shadowing) / EXOHEAT (non-shadowing) surface temperature calculation and creates Albedo-Earthshine File for input to BIDIRC.

SELECT - Accesses Optical Properties Data Base and prepares input file for BIDIRC.

TSHAD - Synthesizes shapes and material inputs for EXOHEAT3 and SELECT and prepares geometry file for BIDIRC.

RVSNTH - Synthesizes shapes and material inputs for EXOHEAT and SELECT and prepares geometry file for BIDIRC.

EXOHEAT3 - Calculates surface temperatures (shadowing).

EXOHEAT - Calculates surface temperatures (non-shadowing).

The image chips generated will be time-sequenced images of a single midcourse object as perceived by the sensor throughout the engagement. These images will be computed at a spatial resolution five times higher than the final sensor output resolution to minimize aliasing errors during scene compositing. An example of an image chip generated for a typical RV replica decoy is shown in Figure 6. The object is a teflon coated medium class RV replica decoy in a polar attack on CONUS at local noon.

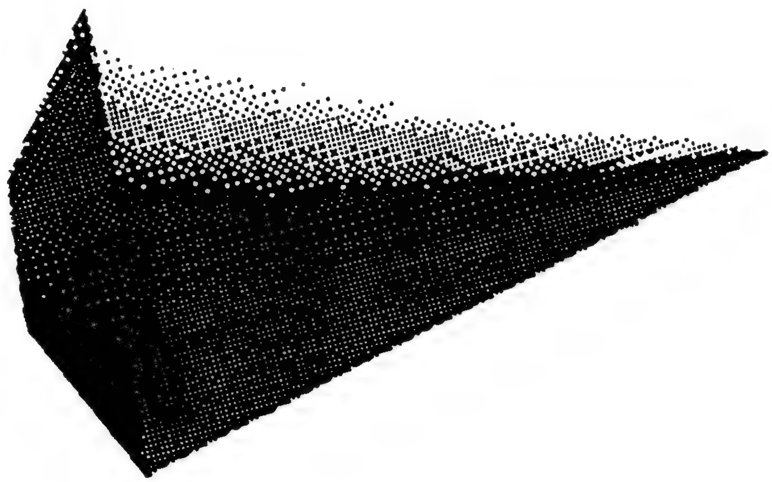

FIGURE 6. AN EXAMPLE BIDIRC IMAGE CHIP OF AN RV REPLICA DECOY.

3.4.2 POINT-SOURCE OPTION

The point-source option first computes the target intensity along the direction of the sensor LOS, then converts this intensity to pixel radiance for the sensor output pixel in which the target resides.

The intensity is computed by interpolating an off-line generated data base called the Ground Surveillance Tracking System (GSTS) point-source data base. This data base is stored in the Run-Time Library. This data base is for a fixed atmospheric state and earthshine environment. Data base intensity is given as a function of wavelength and target orientation relative to the sensor LOS and the sun for pre-established trajectories. Although this GSTS data base is restricted, it can be expanded to represent a broader range of targets, trajectories, and environmental conditions.

The interpolation software is called SIGNAT and exists as a subroutine of the FRMGEN module. It was developed by TBE, based upon OSC outputs, specifically for operation upon the GSTS data base. An example of a time dependent point-source intensity of the Figure 6 decoy is shown in Figure 7.

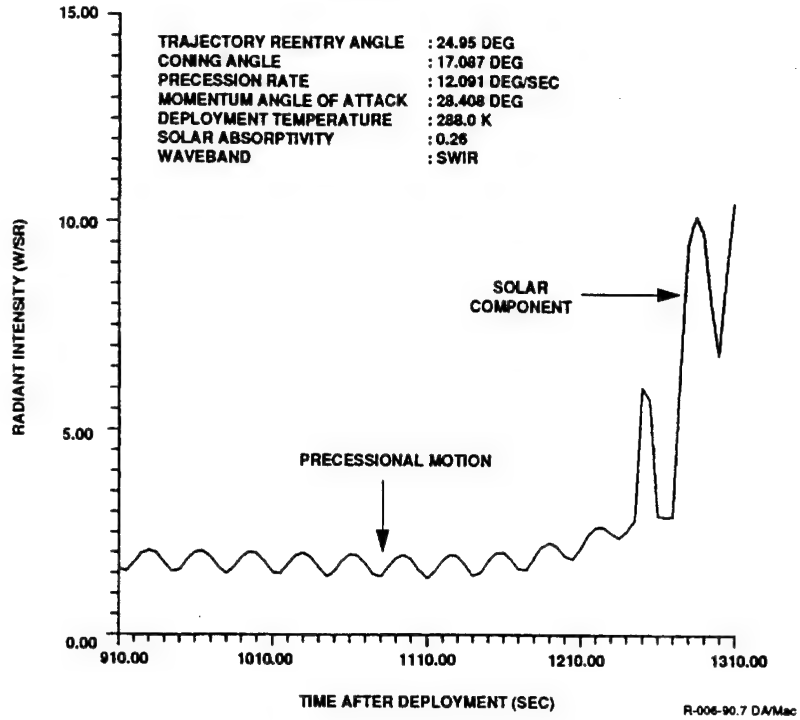

FIGURE 7. POINT-SOURCE INTENSITY CALCULATED BY SIGNAT FROM THE GSTS DATA BASE FOR AN RV REPLICA DECOY.

4.0 GENESSIS DESCRIPTION

GENESSIS is a collection of computer codes which generate images of terrestrial surfaces. In particular, GENESSIS calculates N by M viewer-perspective pixel apparent radiance maps as large as 1024 by 1024 pixels. The apparent radiance is the source radiance attenuated by atmospheric scattering and absorption, and augmented by atmospheric emission along the path between the background and the viewer. The apparent radiances consist of four terms, combined additively. These are: the reflected solar, thermal emission, reflected sunshine, and path radiance. The data bases within GENESSIS support image simulation within the spectral band 0.4-15 microns, with a spectral resolution of 5 cm^{-1} or greater.

Scene simulation is based upon a point-by-point algorithm, a single cycle of which consists of collecting the inputs at a single point on the scene, calculating the apparent radiance associated with that point and assigning the calculated radiance to the appropriate pixel in the observer's field-of-view.

Scene data consists of altitude and material type specified at regular intervals on a planar rectangular grid. Continuous surfaces are produced from this discrete scene data using a bicubic spline fitting technique. Results at arbitrary points can be computed from these surfaces at any user-specified spatial resolution. However, for SSGM applications this resolution is set to equal the input data base resolution. For the scenes provided with the SSGM this resolution is 30 meters and is sampled to the sensor output resolution during composite scene generation.

GENESSIS physical treatments are shown in Figure 8. The "first-principles" approach in GENESSIS requires that all non-radiometric simulation parameters are completely specified and scene radiance is calculated on a point-by-point basis. This procedure produces "real" scenes in the sense that the topography is totally specified and is that of a specified location.

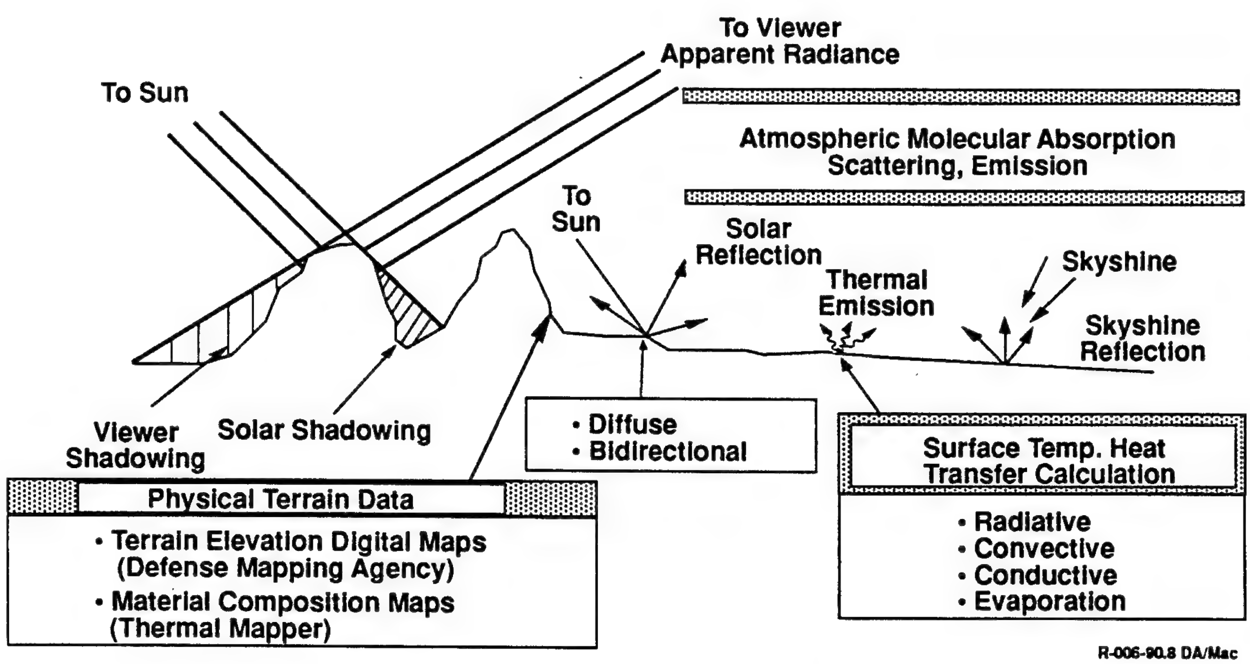

FIGURE 8. GENESSIS PHYSICAL TREATMENTS.

Surface geometry is specified in the form of a digitized topographical map. These are typically obtained from either the Defense Mapping Agency or the U.S. Geological Survey. Altitudes are given at regular intervals, ranging from 30 meters to 100 meters.

Surface composition is specified by assigning two materials (from a GENESSIS population of 21) to each altitude-specified grid point. At each grid point a texture parameter is also specified which defines the percentage of the area in the vicinity of the grid point covered by the first specified material. Surface material assignments are specified from multispectral measurements of the scene, provided by such sources as Thematic Mapper.

At each point on the scene, surface temperature is calculated employing a heat transfer model which includes radiative, convective, and conductive heat transfer, except for water, ice, and snow. Key inputs to this process are the local surface air temperature and wind speed. At the present time, heat transfer is performed for all scene materials except for water, snow and ice. Water temperature is simply specified on input and snow and ice temperatures are specified as air temperature below freezing and their melting points above freezing.

GENESSIS is capable of using three types of reflectance data:

- o Diffuse reflectance (dependent on wavelength)
- o Directional reflectance (dependent on incoming zenith angle and wavelength), and
- o Bidirectional reflectance (dependent on incoming and outgoing zenith angles, net azimuthal angle, and wavelength).

Furthermore, GENESSIS accepts both unpolarized and linearly polarized reflectances. This leads to six reflectance types:

1 - Diffuse unpolarized
2 - Directional unpolarized
3 - Bidirectional unpolarized
4 - Diffuse polarized

5 - Directional polarized

6 - Bidirectional polarized

For all materials except water, only diffuse reflectance data are available for use. For water the full polarized bidirectional treatment is used.

GENESSIS module interaction and data flow is shown in Figure 9. The generation of a pixel radiance map occurs in four primary steps. These are geometric processing, surface parameter processing, radiance processing, and image processing. In addition to these steps, two additional off-line processing steps are required. These are for the creation of the atmospheric coefficients file and the heat transfer data file.

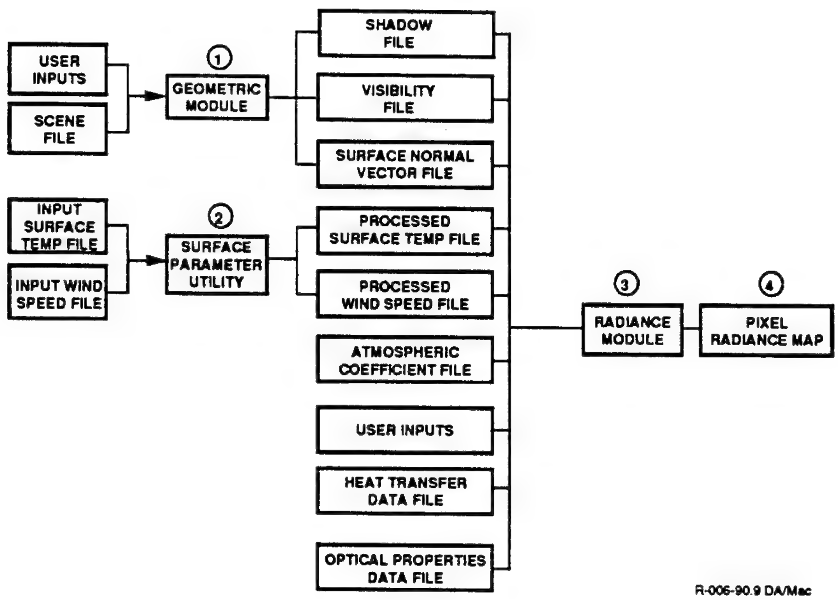

FIGURE 9. GENESSIS MODULE INTERACTION AND DATA FLOW.

The atmospheric coefficients file is calculated with a utility code called APART (Atmospheric Propagation and Radiative Transfer) and consists of four quantities as a function of altitude (spanning those altitudes of the digital terrain elevation), each at a single solar elevation and viewer elevation. These values are interpolated over altitude when point-to-point radiance is calculated. The quantities are:

L_{path} = atmospheric path radiance, including solar single scattering
τ_{path} = atmospheric path transmission
H_{SLR} = the apparent solar irradiance for unit reflectance for the path space-surface-viewer
H_{sky} = the apparent reflected hemispheric skyshine radiance for unit reflector

The heat transfer data file is precomputed with the GENESSIS heat transfer algorithms and contains surface temperature (by material type) as a function of wind speed, surface air temperature, subsoil temperature, peak solar irradiance, and solar elevation angle.

The computation of radiance at each point in the scene is achieved by evaluation of the following equation:

$$L_{app} = \frac{1}{\pi} [H_{SLR} * \rho_{bkg} * \cos(\theta_{SLR})] + H_{sky} * \rho_{bkg} + L_{bb} * \epsilon_{bkg} \, \tau_{path} + L_{path} \qquad (1)$$

where

L_{app} = apparent background radiance, watts/cm^2 sr
H_{SLR} = apparent solar reflected irradiance, watts/cm^2 for unit reflector,
H_{sky} = apparent reflected hemispherical skyshine, watts/cm^2 for unit reflector,
L_{bb} = terrain blackbody radiance, watts/cm^2 sr
L_{path} = atmospheric path radiance, watts/cm^2 sr
ρ_{bkg} = surface material reflectance,
ϵ_{bkg} = surface material thermal emissivity, computed as $(1.0-\rho_{bkg})$
θ_{SLR} = solar zenith angle
τ_{path} = atmospheric path transmission.

At the point where equation (1) is evaluated, all independent values are in-band. However, each in-band value was obtained by first performing a spectral evaluation of the value and then either integrating it over the spectral band (i.e., H_{SLR}, H_{sky}, L_{bb}, L_{path}) or averaging it over the band (i.e., ρ_{bkg}, ϵ_{bkg}, τ_{path}).

Examples of GENESSIS outputs are shown in Figures 10 and 11. Figure 10 displays a 1024 by 1024 image array at 400 meters resolution in the 10-12 μm region. Figure 11 displays a 512 by 512 image array at 30 meters resolution in the 3.6-4.0 μm region.

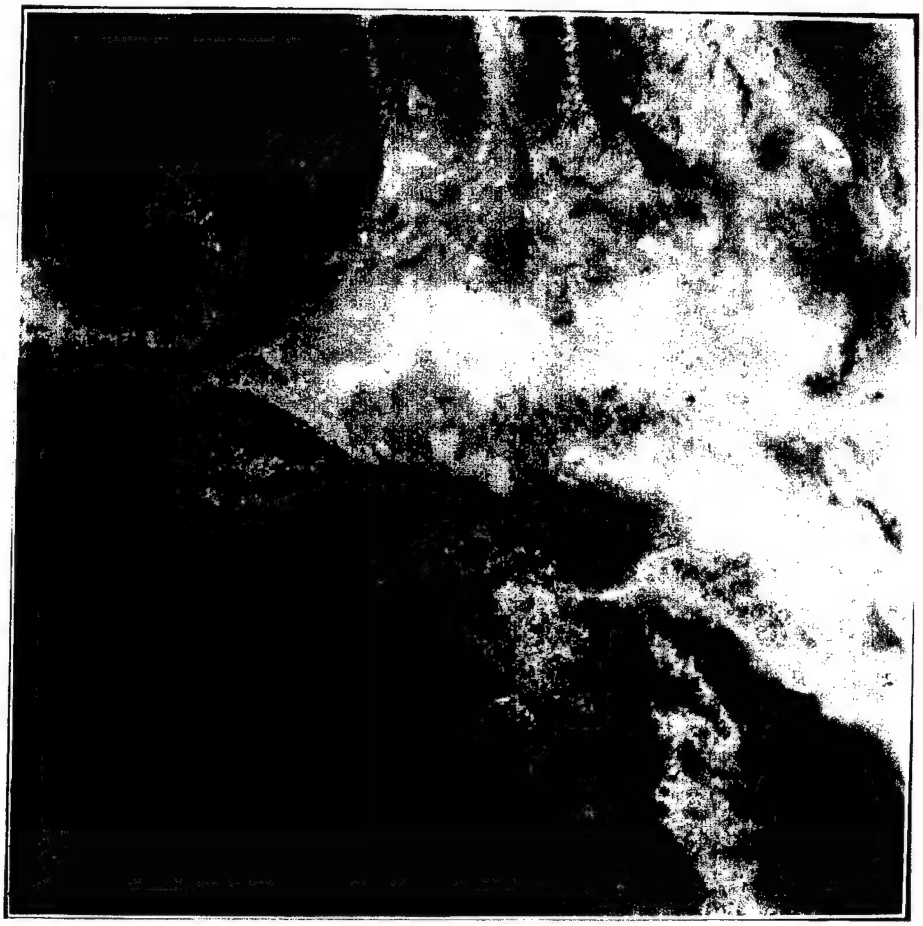

FIGURE 10. GENESSIS IMAGE OF SOUTHERN CALIFORNIA. 1024 BY 1024 AT 400 METERS. 10-12 μm BAND.

5.0 CLDSIM DESCRIPTION

CLDSIM calculates an N by M array of apparent LOS radiance at each point in a uniform x,y array of cloud top altitudes. These radiance values are stored in the Run-Time Library. Unlike GENESSIS, CLDSIM does not produce a viewer-perspective pixel radiance map. This is done as part of the frame generation process.

FIGURE 11. GENESSIS IMAGE OF CAMARILLO, CALIFORNIA. 512 BY 512 AT 30 METERS. 3.6-4.0 μm BAND.

The physical treatments in CLDSIM are shown in Figure 12. The cloud top is represented as a surface, specified simply as altitude on a uniform x,y array. The optical properties of this surface are represented by a bidirectional reflectance density function (BDRF) calculated off-line with a volumetric plane-parallel multiple-scattering radiative transfer model applied to spherical cloud particles.

Cloud top temperature is set equal to air temperature at that altitude, taken from a model atmosphere temperature profile. CLDSIM radiance includes solar reflection, skyshine reflection, thermal emission, cloud-attenuated earthshine, and path radiance.

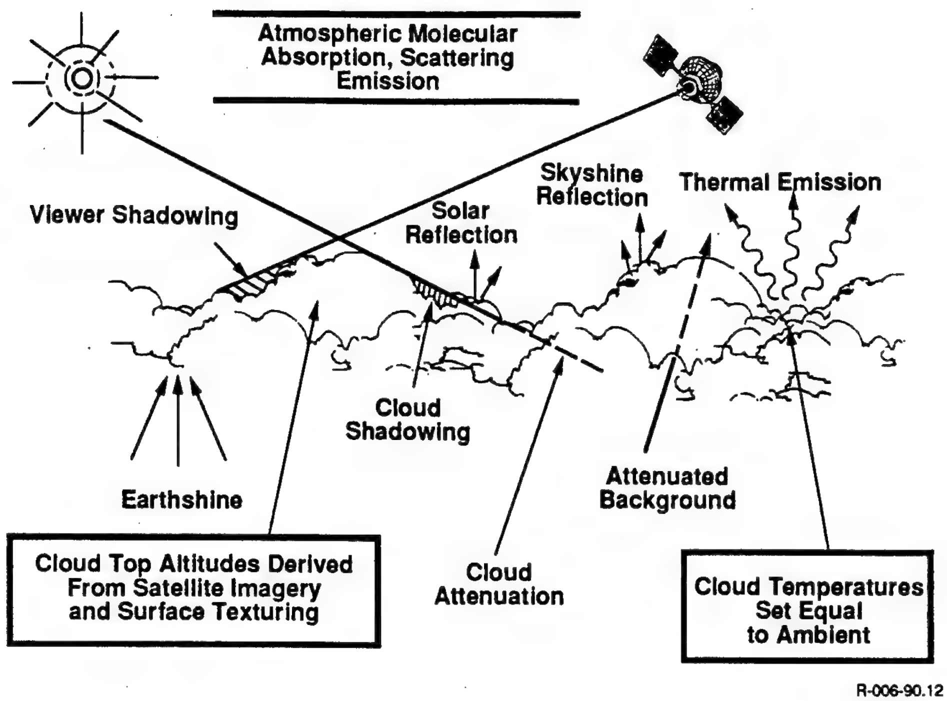

FIGURE 12. CLDSIM PHYSICAL TREATMENTS.

The cloud scene file can consist of multiple cloud types, each type having its own BRDF. In those spatial locations where no cloud exists CLDSIM computes a path radiance quantity only. The lower boundary of this path is the earth's surface. When clouds are overlayed on terrain backgrounds as calculated by GENESSIS, the earth's surface radiance is that from GENESSIS. Otherwise it is assigned a user-input background radiance.

CLDSIM module interaction and data flow is shown in Figure 13. User inputs (consisting of viewer latitude, longitude, altitude; scene center latitude, longitude; and date, time) and a cloud scene file (consisting of altitudes on a uniform x,y grid) are input to a geometric module which computes a geometric data base consisting of cosines (at each grid point) for the following vectors: sun-surface normal, viewer-surface normal, sun-viewer, sun-local vertical, and viewer-local vertical. This geometric data base and cloud altitudes are input to the radiance module.

The APART code calculates an atmospheric coefficients file (described in Section 4.0) which is merged with the BRDF data base and atmospheric lapse

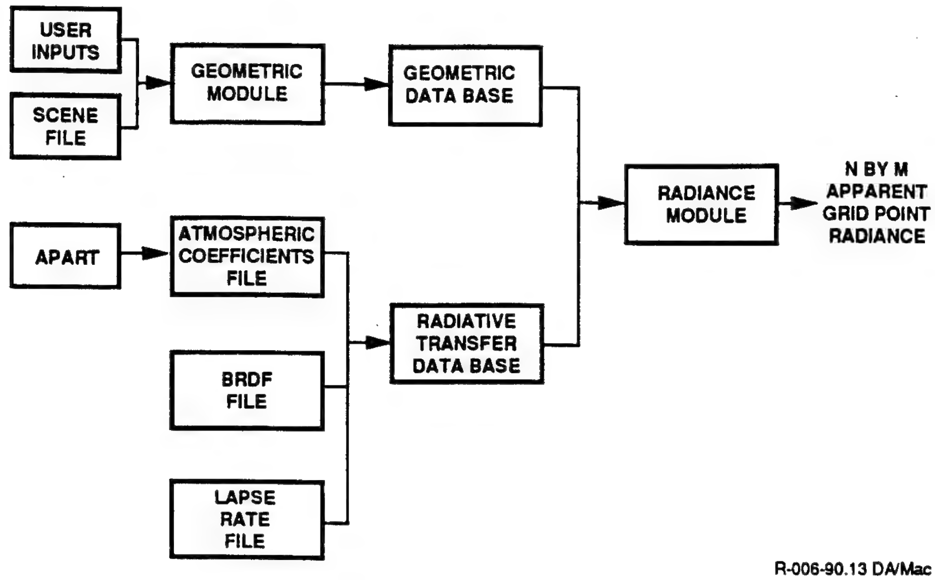

FIGURE 13. CLDSIM MODULE INTERACTION AND DATA FLOW.

rate to form a radiative transfer data base, which is also input to the radiance module. The radiance module then calculates the final apparent grid point radiance array.

The atmospheric coefficients file contains quantities at selected values of solar elevation, viewer elevation, and altitude (spanning those values possible as determined from the scene altitude file, the solar vector, and the viewer vector). These values are interpolated when calculating radiance from point-to-point over the cloud surface. The quantities are:

L_{path} = atmospheric path radiance, including thermal emission and solar single scattering

τ_{path} = atmospheric path transmission

L_{BB} = blackbody radiance at air temperature corresponding to input altitude.

H_{SLR} = the apparent solar irradiance for the path space-surface-viewer for unit reflector

H_{sky} = the apparent reflected hemispherical skyshine radiance for unit reflector

The specific equation evaluated by the radiance module at each grid point on the cloud surface is:

$$L = [H_{SLR} \rho_{BD} \cos\theta_{SLR}] + H_{sky} \rho_D + L_{BB}(T_{CLD}) \epsilon_D \tau_{path}(\theta_v) + L_{path}(\theta_v)$$

where

H_{SLR}	is the apparent solar irradiance (for the path space-surface-viewer) for unit reflector (W/cm^2)
ρ_{BD}	is the cloud bidirectional reflectance (1/sr)
θ_{SLR}	is the angle between the surface normal vector and the vector to the sun
H_{sky}	is the apparent reflected hemispherical skyshine radiance for unit reflector (W/cm^2 sr)
ρ_D	is the directional reflectance
L_{BB}	is Planck's function (W/cm^2 sr)
T_{CLD}	is the cloud top temperature derived from the lapse rate (Kelvins)
ϵ_D	is the directional emittance (1-ρ_D)
$\tau_{path}(\theta_v)$	is the path transmission for the path cloud surface to viewer
$L_{path}(\theta_v)$	is the path radiance from the cloud surface to viewer (W/cm^2 sr)
θ_v	is the angle between the local vertical and the vector to the viewer

In addition to radiance, the radiance module calculates and outputs cloud transmission. This is used in the overlay process when the cloud radiance is overlayed on the GENESSIS terrain background.

Cloud transmission is calculated by

$$\tau_{cld} = e^{-\alpha t/\cos\theta_v},$$

where

α = cloud extinction coefficient in 1/meters, calculated by the cloud radiative transfer model.

t = cloud thickness (meters)

Figures 14 and 15 are examples of CLDSIM output images. Figure 14 is a 1024 x 1024 image at 400 meters resolution in the 2.6-2.8 μm band of a cumulonimbus cloud scene. Figure 15 is a 4000 x 4000 image at a nominal resolution of 400 meters in the 2.6-2.8 μm band of a multiple cloud type horizon scene. The image in Figure 15 was "footprinted" into the focal plane projection by the FRMGEN module and composited with the above-the-horizon earthlimb.

FIGURE 14. CLDSIM IMAGE OF CUMULONIMBUS CLOUD SCENE. 1024 BY 1024 AT 400 METERS. 2.6-2.8 μm BAND.

6.0 COMPOSITE SCENE REPRESENTATIONS

Several composite scene images were generated with an operational prototype of the SSGM currently under development. These images are typical examples of future SSGM products. The example set consists of a solid missile plume superposed on a nadir view of a GENESSIS terrain background, a nadir view of a CLDSIM cloud background, and a horizon view of a CLDSIM background after being footprinted by FRMGEN. The set also includes a time sequence of a solid missile plume superposed on a terrain-cloud composite at multiple times during its trajectory. The missile is increasing in altitude during the sequence. These images are shown in Figures 16, 17, 18, and 19, respectively.

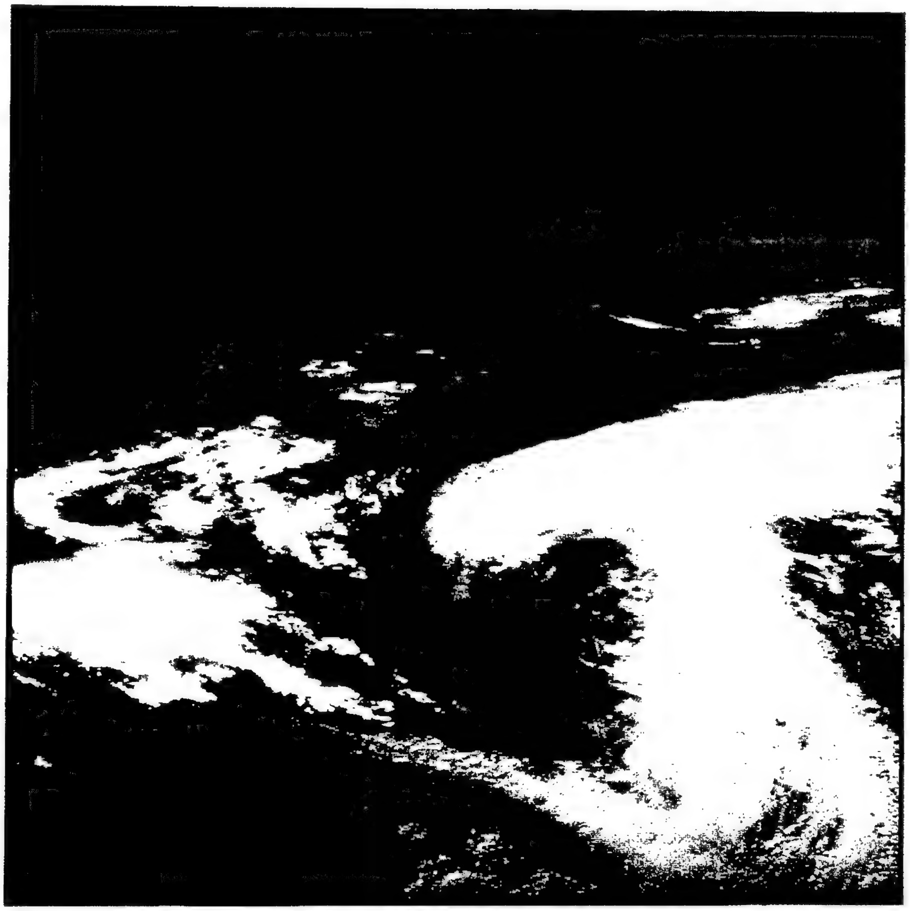

FIGURE 15. CLDSIM IMAGE OF MULTIPLE CLOUD TYPE HORIZON SCENE. 4000 BY 4000 AT 400 METERS. 2.6-2.8 μm BAND.

FIGURE 16. SOLID MISSILE PLUME ON TERRAIN BACKGROUND. NADIR VIEW, 120 km ALTITUDE PLUME, 61° ASPECT, 2.4 km RANGE TO PLUME.

FIGURE 17. SOLID MISSILE PLUME ON CLOUD BACKGROUND. NADIR VIEW, 120 km ALTITUDE PLUME, 61° ASPECT, 2.4 km RANGE TO PLUME.

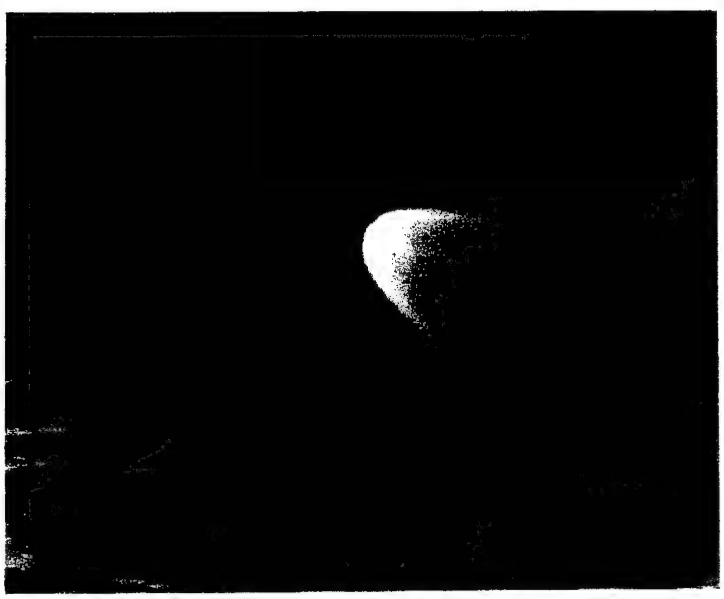

FIGURE 18. SOLID MISSILE PLUME ON HORIZON BACKGROUND. NADIR VIEW, 120 km ALTITUDE PLUME, 78° ASPECT, 23 km RANGE TO PLUME.

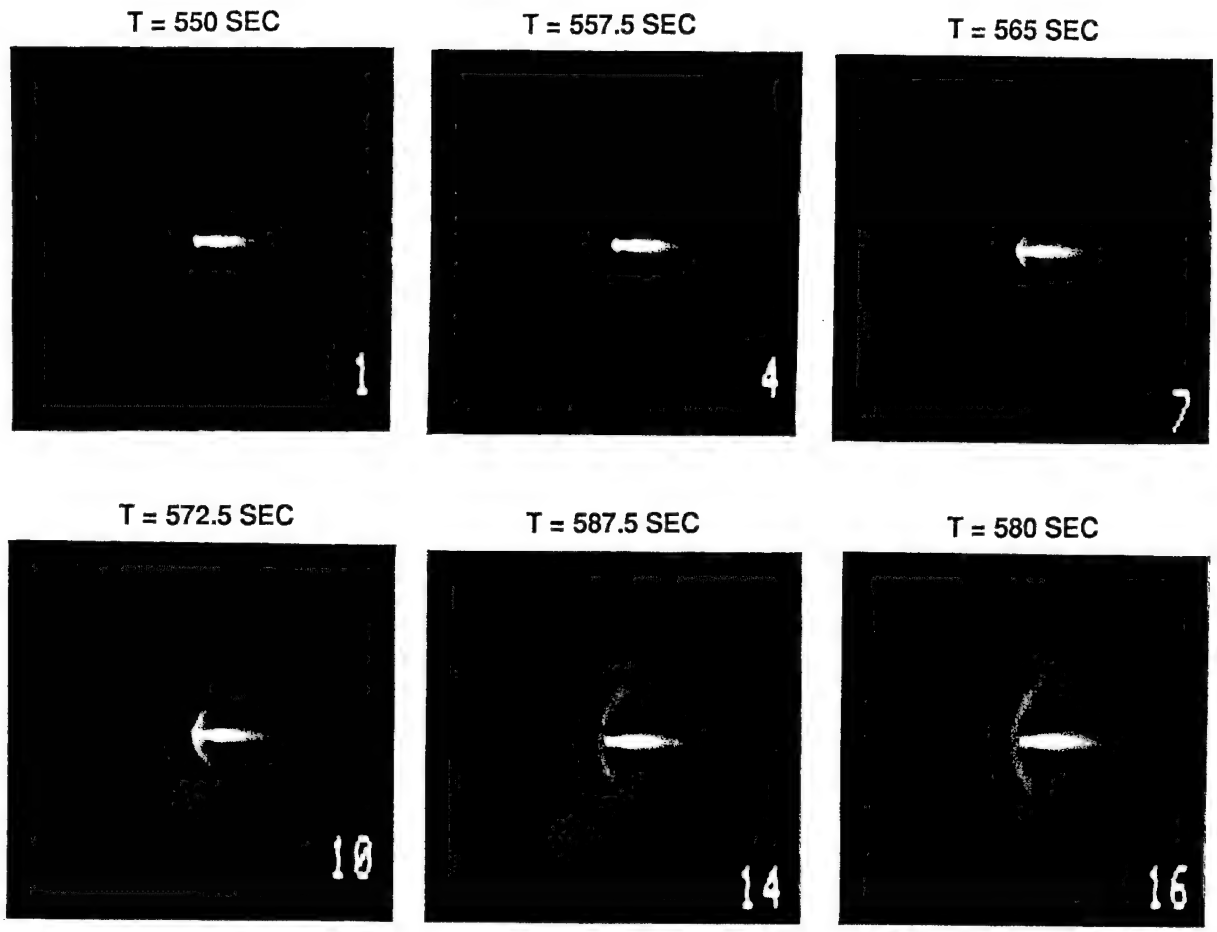

FIGURE 19. TIME SEQUENCE OF SOLID MISSILE PLUME ON TERRAIN-CLOUD BACKGROUND. NADIR VIEW.

EARTHLIMB AND AURORA BACKGROUND SCENE GENERATION

JANUARY, 1990

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ABSTRACT

Surveillance systems, especially for mid-course detection missions, must acquire and track targets against a naturally structured earthlimb and aurora background. The background levels are highly variable both in wavelength and radiance. "Standard" one-dimensional line-of-sight models for describing such backgrounds have been developed by organizations such as the Geophysics Laboratory, Naval Research Laboratory and Defense Nuclear Agency. As part of the newly established SDI/NRL Strategic Scene Generator Model effort, we have developed techniques for applying these background models to represent multi-dimensional earthlimb and aurora background scene realizations. We present these model techniques and sample scene results for both earthlimb and auroral phenomenology. Naturally occurring statistical structure for both earthlimb and aurora modelling is described as it effects clutter representation in the scenes. Specific systems-oriented scene realizations are illustrated.

1.0 INTRODUCTION

One of the main requirements for modelling systems-perspective atmospheric earthlimb and auroral backgrounds is the development of accurate two-dimensional realizations of three-dimensional phenomena. This includes both the radiance values and the variability in time and

space. Most atmospheric backgrounds codes represent one-dimensional line-of-sight radiance along a trajectory that assumes a uniform atmospheric profile. A requirement exists to extend these code predictions to two-dimensional focal-plane realizations of structured backgrounds that account for non-uniform profiles and variability. The objective of this effort, as part of the SDI/NRL Strategic Scene Generation Model (SSGM), is to develop techniques to meet this requirement. We have designed an architecture to use the current state-of-the-science phenomenology models to meet the objective. "Hooks" will be built in to the architecture so that as phenomenology models are updated, they will be easily accommodated within the SSGM.

One of the key issues for scene generation is the accurate representation of variability in the radiance. Large gradients in the background are best represented by a deterministic approach. This maintains the proper "edge effects" such as gradients along auroral arcs, streamers and rays. More general variability can be represented stochastically. We have included both deterministic and stochastic representations for the structure in the scenes. Deterministic representations are based on general morphological observations. Stochastic representations are based on PSD overlays with parameters derived from data, and theory where data is not available.

We describe here the architecture, logic sequence and code implementation in the SSGM for Earthlimb and Aurora structured scene generation. We also present representative scenes along with data samples to indicate the profiles and structure in the scenes. The Earthlimb scenes consist of data bases extending from the hard earth to ~500 km in these examples. The capability exists to represent both daytime and nighttime views with a choices of atmospheric states up to 750 km. The Aurora scenes consist of data bases extending over the region of auroral excitation with both drizzle and multiple arc capability with variable perspective geometries.

2.0 EARTHLIMB SCENES

2.1 EARTHLIMB RADIANCE PROFILES: Earthlimb scenes are produced by first calculating limb radiances at a series of tangent altitudes, then interpolating for full vertical representation. The vertical profiles are then horizontally expanded using a flat-earth coordinate system. Two-dimensional PSD representations of the earthlimb stochastic radiance variations are used to add structure to the earthlimb scenes. Finally, the structured scene is transformed to an earth-centered coordinate system for the scene-specific perspective.

Current earthlimb data bases are one-dimensional LOS radiance profiles calculated by the codes LOWTRAN6 (Kneizys, 1983), HAIRM87 (Clough, 1981, and Humphrey, 1981) and NLTE44 (Wintersteiner, 1985). The limb radiance values are calculated beginning at the lowest tangent height (0 km) and proceeding to the highest (750 km) in increments determined by the spatial resolution and the structure boundaries. From 0 km to 200 km, the limb radiance variations are relatively rapid and require calculations at 10 km increments or smaller. From 200 km to 750 km, limb radiance lapses smoothly and relatively uniformly. The profile is therefore calculated at nominally 50 km increments. These radiance profiles are log/linear interpolated to the appropriate resolution before horizontal expansion. For large scenes, latitude variation may be important. In this case, multiple LOS radiance profiles are generated and horizontally interpolated. We are currently generating the capability for interpolation across the day/night terminator.

For a space-based system operating in a limb geometry, the observed background radiance level is an integration along the line-of-sight of the individual emitting and absorbing processes. For altitudes below the thermal atmosphere (approximately 50 km), background radiance levels are dominated by local thermodynamic equilibrium (LTE). In this altitude regime, a single temperature is sufficient to describe the emission calculation. For this region of the atmosphere, the LOS spectral radiance profiles are generated with LOWTRAN6. The capability

is currently being upgraded to include LOWTRAN7 and APART7. These LTE codes calculate atmospheric radiance and transmittance averaged over 20 cm^{-1} intervals in steps of 5 cm^{-1} from 350 to 40,000 cm^{-1}. LOWTRAN6 uses a single parameter band model for molecular absorption and includes continuum absorption, molecular scattering, solar scattering and aerosol extinction. Refraction and earth curvature, which are quite important in limb geometry, are accounted for in the calculation of an atmospheric slant path. Specified spectral filter functions can be applied to the 5 cm^{-1} spectral files to generate the spectral radiance at each altitude. These files are then integrated to yield the LOS in-band radiance as a function of altitude.

Above ~40 km, the LOWTRAN results are increasingly inaccurate due to departure from LTE conditions. For altitudes above the thermal atmosphere, chemical processes which give rise to background radiance levels are not in thermodynamic equilibrium. The background radiance results from complex chemical-dynamic processes. The emission calculation must include the details of these processes to accurately describe the radiance profile. Vibrational temperatures describing the species must be specified for the radiation transport calculation.

The Non-Local Thermodynamic Equilibrium radiance profile is currently generated through the combination of two codes. The detailed vertical atmospheric description has been constructed using the High Altitude Infrared Radiance Model (HAIRM). HAIRM *implicitly* computes vibrational populations and temperatures of the infrared emitting species. HAIRM will be replaced with ARCHON (Kennealy, 1989, described below) to *explicitly* generate the vibrational-level distributions.

The HAIRM code is capable of generating band-model LOS radiance. However, for NLTE applications, a line-by-line radiation transport calculation is more appropriate, especially for filter-function application. To generate line spectra for the non-LTE atmosphere, the Non-Local Thermodynamic Equilibrium (NLTE) radiation transport code (a radiation transport subroutine in the GL ARC code) is used to calculate

LOS radiance. The detailed vertical atmospheric description constructed by HAIRM or ARCHON is used as input for the NLTE radiation transport code to generate LOS spectral radiance profiles. This part of the model will be replaced with SHARC (Sharma, et.al., 1989). "Hooks" will be included for user selection of other codes such as FASCODE.

Below ~70 km, the NLTE results are less accurate, as line profiles become broadened and overlapped. However, NLTE is applied to calculate radiance from 40 km - 70 km for interpolation with the LTE results in that transition region. A logarithmic average interpolation is applied at the LTE/non-LTE transition region (40-70 km) to generate the representative one-dimensional LOS radiance profile for the spectral bands. The combination of the LOWTRAN (LTE) output and the HAIRM/NLTE (non-LTE) output is a one-dimensional profile of spectral line-of-sight radiance versus altitude. These profiles are horizontally expanded to a two dimensional unstructured flat-earth coordinate system to represent the appropriate lateral extent.

2.2 EARTHLIMB STOCHASTIC STRUCTURE GENERATION: Two-dimensional PSD representations of the earthlimb statistical variability are used to add stochastic structure to the earthlimb scenes. The two-dimensional earthlimb profiles are structured in a process treating the integrated radiance over the LOS. The statistical form of the PSD applied is based on a MRC model derived from the PRi code, STOCH (Stephens, et. al., 1989) and Kilb and Wittwer model (1986). The PSD is spatially non-stationary with altitude (i.e., the inner scale sizes and variance are a function of altitude). Details of this methodology are contained in a DNA report currently in final revision (Armstrong et al., 1989).

Typical outer scale sizes for the non-isotropic behavior depicted in the Earthlimb scenes are L_z = 7.95 km/rad and L_x = 4.35E+03 km/rad. Simplified analytical expressions are developed to specify the variance. They are based on data obtained from atmospheric observations. At altitudes below 140 km,

$$\sigma^2 = 10^{-[(z/60)-4.8]} \qquad 2.2.1$$

and above 140 km,

$$\sigma^2 = 5E\text{-}4 + 10^{-[(185-z)/17]} \qquad 2.2.2$$

where z represents the altitude in kilometers.

Figure 2.2.1 is a representative structured earthlimb radiance profile over the lower (0-150 km) altitude region of the scene. The plot of radiance (W cm^{-2} sr^{-1}) versus altitude (km) are representative of profiles from Earthlimb scenes generated.

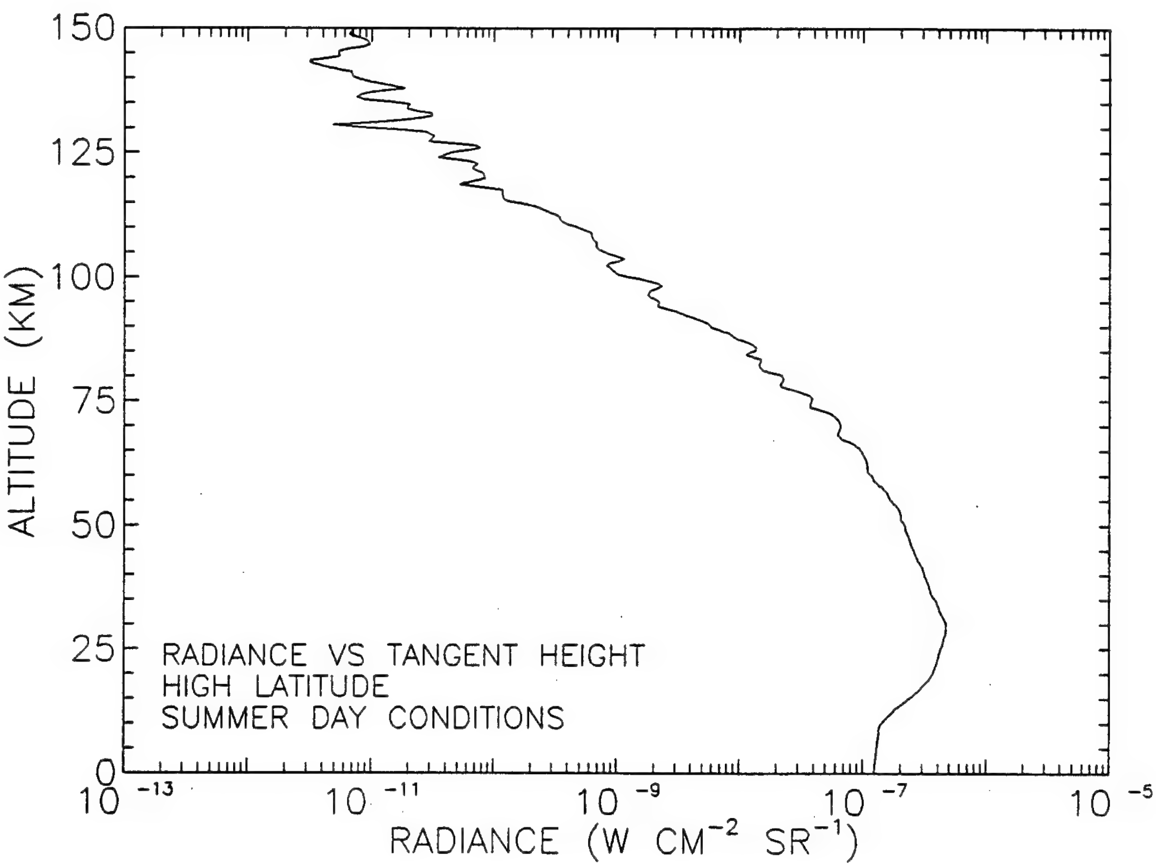


Figure 2.2.1. Earthlimb SWIR Structured Radiance Profile (0 - 150 km)

2.3 SCENE GENERATION: The earthlimb scenes represent in-band line-of-sight radiance data including the spatial structure of the respective limb phenomena. The earthlimb scenes are first structured and then mapped to a curved earth geometry.

To represent the appropriate curved earth geometry for a particular sensor-target orientation, a corresponding map of tangent heights must first be determined. For each pixel in the scene, the associated tangent height is calculated based on the defined sensor and target latitudes, longitudes, and altitudes. The curved-earth geometry is modelled based on a technique developed by PRA (Anding, 1989) and implemented in the SSGM prototype ELIMB code.

The angle of deviation of a LOS from the NADIR is calculated in terms of the viewer altitude, the elevation angle of the image plane center from the NADIR aspect, the user defined IFOV, and the horizontal and vertical pixel displacements from the scene center. From this, the displacement of each point in the image plane from the earth's center is determined. This forms the basis for a point-for-point re-mapping of the flat image to represent the viewer-perspective curved earth.

For each pixel in the scene, the tangent height calculated has an associated value defining the angles in the image coordinate system contained in the viewer coordinate system. These values specifically define the offset number of columns and rows from the image center pixel. From this point, the tangent height grid is constructed and used to adjust the structured flat earth scene. For each radiance point in the scene, each pixel is vector remapped point-for-point based on the associated tangent height, to account for the earth curvature. This remapping is performed in the vertical dimension only. For a particular scene realization, the radiance associated with the two altitudes in a vertical column corresponding most closely with this calculated tangent height are weighted in a log-linear manner to best depict the viewer perspective. The tangent height interpolation calculated at each pixel in the scene is carried out in intervals <1% of the pixel resolution.

Thus, fine structure detail contained in the scene is preserved and limited only by the pixel resolution.

3.0 AURORA SCENES

3.1 AURORA RADIANCE PROFILES: Aurora radiance scenes are produced by first calculating one-dimensional profiles of volumetric radiance vs. altitude in the auroral region. A two-dimensional realization is created by geometrically defining the auroral arcs using a 3-D analytic descriptive function based on a Gaussian roll-off and integrating over the line-of-sight path. The line-of-sight geometry depicted in the scene can vary from normal-to to tangent-to the auroral oval. Two-dimensional PSD representations of the aurora radiance structure are used to add stochastic structure to the aurora deterministic scenes. The aurora data base is overlaid with the appropriate geometry upon the corresponding earthlimb data base described in the previous section.

The initial aurora data base is a one-dimensional volumetric emission profile calculated by using the MRC auroral code ARCTIC (Archer et. al., 1977) and the MRC ARCHON code (Kennealy et. al., 1989) - a first principles chemical dynamics code. In this methodology, ARCTIC is used to describe the aurora atmospheric profile. The ARCHON code is then used to calculate the atmospheric dynamics occurring in the aurorally disturbed atmosphere as described by ARCTIC. Volumetric spectral radiance profiles are constructed for the appropriate flux levels: a drizzle background and a variable strength arc of specified duration. Spectral line files are generated by coupling the ARCTIC/ARCHON output to MRC Spectral Modelling Codes (McKenzie et al., 1987).

The auroral phenomena is restricted to the NLTE atmosphere typically above 90 km. Volumetric emission profiles are generated for the spectral bands over an altitude region of 90 - 194 km. The spectral filter specified for a chosen band can be applied to the Aurora spectra generated for each tangent height.

For auroral energy deposition characterization, the MRC ARCTIC code (Archer et.al., 1977) is used. ARCTIC is a general-purpose electron deposition and chemistry code which describes the effects of electron flux in the atmosphere under aurorally disturbed conditions. The phenomenology included within the ARCTIC code are electron energy deposition and energy partitioning, (including secondary electron generation, subsequent induced neutral and ion chemistry, electron heating effects), and ultimately optical and infrared emission levels.

The standard ARCTIC output is total band volumetric emission. Thus the spectral information necessary for filter function application is not an output option. In order to obtain the spectal detail for line-file generation, the electron deposition profile and species production rates from ARCTIC are coupled to the MRC/DNA ARCHON code (Kennealy, et.al., 1989) and the MRC Spectral Modelling codes, DOUBPI and SINGLET (McKenzie, et.al., 1988).

ARCHON is a flexible first principles chemical physics kinetics code with a numerical method based on a Taylor Series Expansion. The output of the ARCHON calculation is a complete time/concentration history of each species. Each vibrational level of atmospheric constituents is treated as a separate species so that the output is easily coupled to spectral codes. The specific vibrational populations for the species of interest were extracted from the ARCHON results for input to DOUBPI and SINGLET to generate spectral line files.

The MRC spectral modelling codes (McKenzie et. al., 1987), DOUBPI and SINGLET, are used to calculate detailed spectra and wavelength-dependent emission coefficients for the emitting species. The input parameters consist of the maximum vibrational and rotational levels to be modelled and the corresponding vibrational distributions and rotational temperature. The spectral distribution is then calculated from the spectral position and intensity.

Aurora line spectra are typically generated for 25 altitudes over the range 90 - 194 km at a resolution defined by the auroral radiance gradient. This corresponds to 2 km increments from 90 to 115 km and 5 km increments from 120 km to 190 km. These line spectra are filtered and interpolated in a log/linear manner to create the final output of a one-dimensional profile of filtered in-band volumetric emission (W cm^{-2} sr^{-1}) versus tangent height (km).

<u>3.2 AURORAL STRUCTURE GENERATION:</u> For the aurora, the final database is a two-dimensional scene representing streamers, rays, and arcs. Initially, the one dimensional filtered volumetric emission profiles generated are stretched with a three dimensional raised cosine function with a gaussian roll-off to create single arc representations. This function creates each arc independently in a multiple arc scene and allows the width and depth of each to vary. However, the LOS width and depth for a particular arc are dependent relative to the orientation of the viewer and with respect to the direction of the magnetic field gradient. The dimensions of the arcs and the respective latitudes and longitudes of their centers are representative of actual space-based auroral observations. The result of the application of the analytical cosine function to generate the three arcs is a three-dimensional deterministic matrix of volumetric emission representing specific arc and drizzle contributions.

The lines-of-sight are calculated through this three-dimensional matrix to represent the two-dimensional realization of the sensor-target geometry. The integrated radiance over a particular LOS path includes those effects produced by the earth's curvature in a direction normal to the image plane. Thus, the constructed LOS paths contain radiance contributions from several different altitude components. Since the arc contributions are displaced from the vertical plane of the horizon, the projections of the aurora activity drop to lower vertical pixel elevations. The impact of this is observable at the higher altitudes of aurora activity. At these altitudes, the effective LOS path containing arc and drizzle contributions is greatly reduced from that of the "flat-earth" calculation.

Ray structure enhancement is added to the integrated two-dimensional multiple arc scene with an analytical pseudo-random process. This process is based on the magnetic field gradient as a function of scene depth. It involves generating a set of random coefficients to represent the ray enhancements. By a weighted Gaussian convolution across 10 elements (corresponding to a 2.5 km maximum ray diameter), the discontinuities between neighboring ray elements is removed. Then, depending on the viewer aspect with respect to the magnetic field gradient, the coefficients are summed over the LOS. The number of elements for each integration is determined by

$$N = 4 \times (\text{arc depth}-30) \times \cos\theta \qquad (3.2.1)$$

where θ is the angle between the LOS path and the maximum field gradient (south-to-north). The arc depth is in units of km and the value 30 originates with the assumed arc-depth normal to the oval of 30 km. The elements involved in each summation vary only as a function of horizontal displacement. If α is the first element indexed in the successive summation of N numbers at a point X_0 in the scene and if the horizontal displacement from the point X_0 to X_1 is ΔX, then

$$\alpha(X_1) = \alpha(X_0) + 4\Delta X \qquad (3.2.2)$$

The average of the elements contained in the range $\alpha(X_0)$ to $\alpha(X_0)+N$ for any point in the image plane is then the coefficient of net enhancement due to ray structure for that point. From equation (3.2.2), variations due to the ray structure can only be observed for horizontal displacements greater than 250 meters. Based on investigations of auroral morphology, the diameters of the individual rays generated range from 250 meters to 2.5 km. The form of the Gaussian chosen depicts this ray structure enhancement.

Stochastic structure is added to the aurora deterministic scene through use of a two-dimensional PSD representation of the statistical variability associated with the aurora processes. With the exception

that the altitude-dependent PSD is not required, the PSD form used is identical to that in the Earthlimb application. The PSD scaling parameters were derived by analysis of data collected at visible wavelengths (e.g., Harang, 1951).

Scene variability is driven by the drizzle chemistry only over the LOS since the statistical variability associated with the arc has been described through the deterministic structure. Thus, the resulting variable-pixel radiance map is determined from the integration of the drizzle radiance over the LOS multiplied by the fractional variance. Typical outer scale sizes for the stochastic behavior depicted in the scenes are $L_z \sim 37$ km/rad, $L_x \sim 18$ km/rad. The inner scale sizes are $\ell_x = \ell_z = 1.3$ km/rad. The variance, σ^2, is derived to be approximately 10% of the integrated drizzle contribution.

<u>3.3 AURORAL SCENE GENERATION</u> The aurora scenes consist of in-band line-of-sight radiance representing the spatial and deterministic structure of the aurora phenomena. As with the earthlimb, the aurora scenes are structured and then mapped to the curved earth geometry. The methodology to represent the curved earth geometry is identical to the earthlimb calculation. The PSD for the aurora is assumed homogeneous. However, the statistical variability applied to the aurora changes over the vertical and horizontal scene representation. The minimum correlation distance is determined by the pixel resolution in the scene. Since the minimum correlation length is the pixel resolution, and the interpolation is carried out in intervals <1% of the pixel resolution, all structure information is preserved.

Figure 3.3.1 represents vertical radiance profiles of the earthlimb and the aurora. The SWIR aurora profile is strong relative to the SWIR earthlimb profile. The sharp boundary/dropoff seen at ~160 km is a result of (1) the actual chemistry in the auroral radiance versus tangent height profile and (2) the orientation of the arc in the final LOS geometry profile.

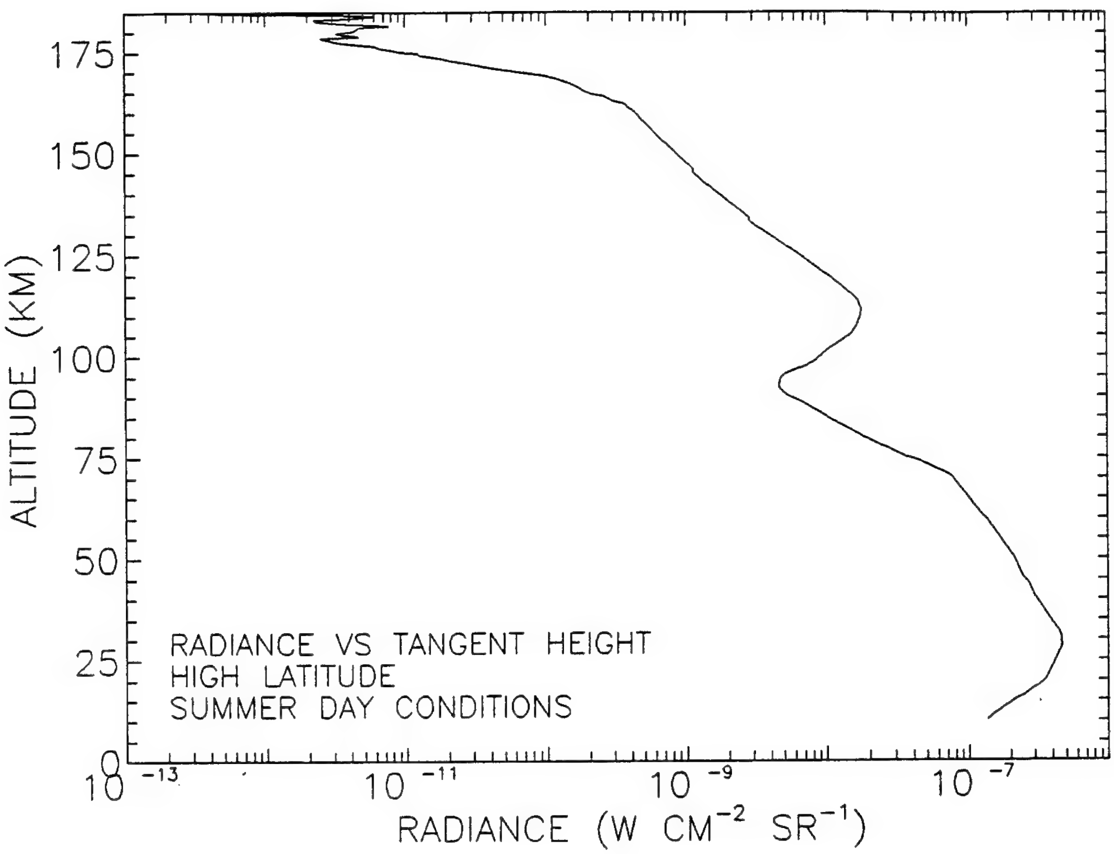
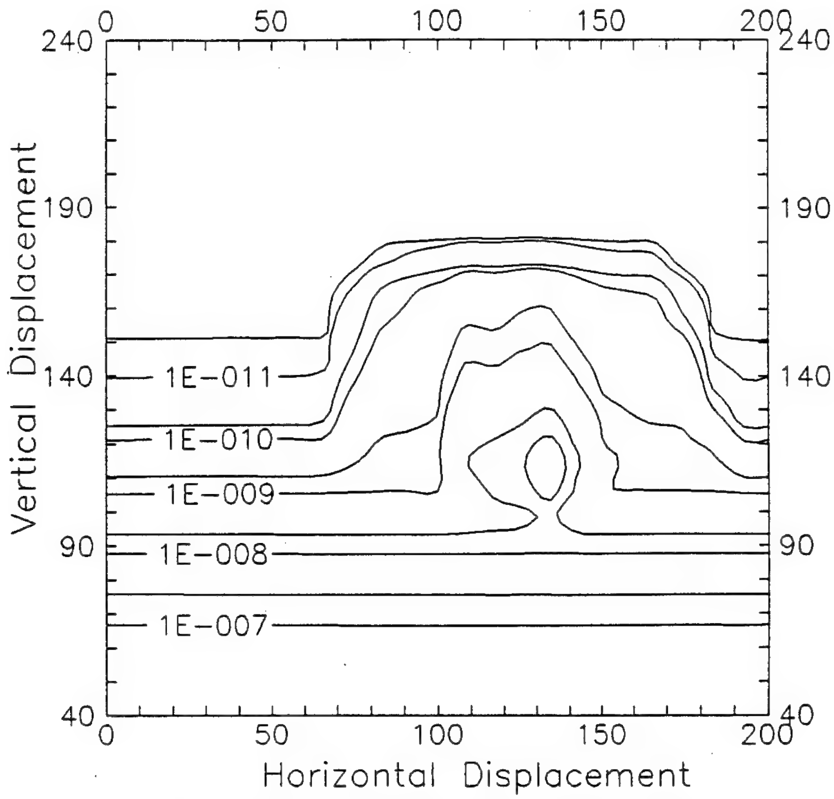


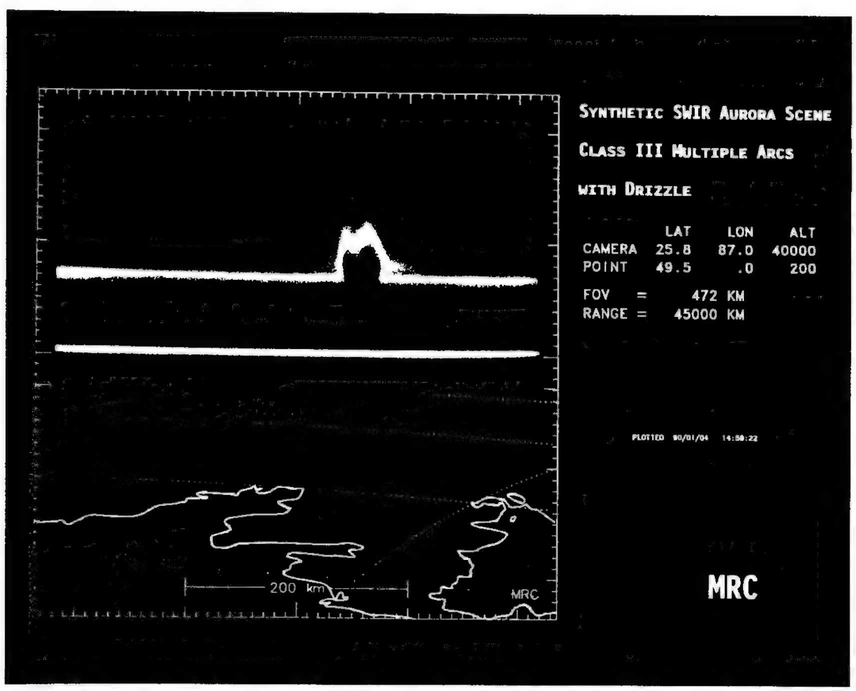
Figure 3.3.1 SWIR Aurora/Earthlimb Scene Vertical Profile at Arc Center

Figures 3.3.2(a) and 3.3.2(b) are the topographical plot and photographic representations of a composite SWIR auroral and earthlimb scene. They represent a 512 km x 512 sub-sample which contains both Earthlimb and Aurora scene contributions.

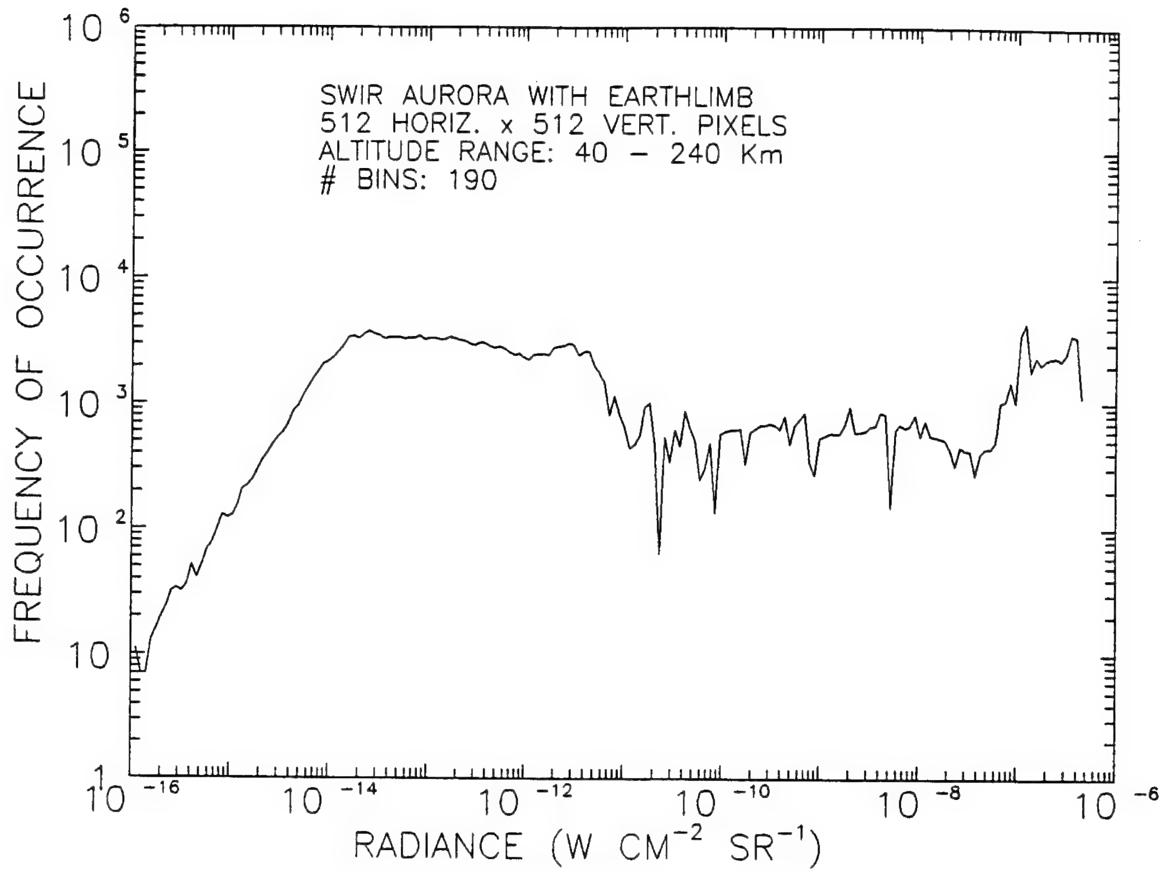
Figure 3.3.3 is a histogram of a 512x512 segment of the SWIR data base. This histogram describes the relative radiance contributions contained in the Earthlimb portion of the scene. The bin resolution chosen for the histogram is selected based on the range of radiance contained in the scene and the total number of points in the direction of the gradient (i.e., the vertical extent). The data ranges in altitude from 0 to ~500 km with ~500 km horizontal extent. The radiance



3.3.2(a) SWIR Scene 2-Dimensional Topographical Plot



3.3.2(b) SWIR Scene Photographic Digital Representation



3.3.3. Histogram of the SWIR Earthlimb and Aurora Data Base.

values range from approximately 10^{-6} to 10^{-13} W cm^{-2} sr^{-1} in the SWIR. Due to the number of decades of radiance represented in these scenes, a logarithmic representation is chosen.

To represent the data, ~190 bins were chosen. This corresponds to a bin resolution of approximately 5% of the logarithmic radiance mean for a given bin. Mathematically,

$$\delta R = 10^{[(nD/B)+\log(m)]} - 10^{[((n-1)D/B)+\log(m)]} \simeq (D/B) \qquad (3.3.1)$$

where δR is the bin resolution of the n^{th} bin, m is the minimum radiance in the scene, D is the number of decades of radiance in the scene and B is the number of bins.

The low radiance side of the histogram increases steadily to a uniform radiance distribution. This is due to the Gaussian contribution of the high altitude variability extending beyond the minimum unstructured scene radiance. The uniform radiance distribution region is an ensemble of Gaussian contributions with a standard deviation two orders-of-magnitude larger than the bin resolution. This uniform distribution also exists since the scene radiance gradient is constant over the high altitude region of the scene where these values occur.

The uniformity of the radiance distribution is terminated by either a decrease in relative variability with increasing radiance or a change in the radiance gradient. As the variability decreases, the Gaussian distribution corresponding to a particular altitude narrows. This forces the variability to approach the bin resolution in the high radiance (low-altitude) regime. In addition, the change in radiance from pixel to pixel associated with the unstructured vertical profile exceeds the bin width. This results in discontinuous contributions to the histogram. The effects are coupled with an increase in the radiance gradient. This results in a decline in the frequency of radiance value occurrence with increasing radiance. The relative maxima at high end of the spectra is due to a near-steady radiance value at the low altitude regime.

4.0 SUMMARY - REQUIREMENTS AND APPLICATIONS

We have demonstrated capability to generate two-dimensional realizations of three-dimensional atmospheric processes using state-of-the-science atmospheric and auroral radiance codes. The architecture to accomplish this capability is designed to be flexible for applications of code improvements and replacements. We have benchmarked the scenes against data where available and the agreement is good. There are still outstanding issues of involving appropriate treatments of structure, non-uniform media line-of-sight integration, proper predictions across the LTE/NLTE boundary, etc. The LOS integration requirements will likely be addressed by the development of SHARC. Additional

experimental data is needed on atmospheric structure to support model validation.

The generation of Earthlimb and Auroral background scenes serves as a test-bed for systems sensitivity studies and concept demonstration and validation. These scenes can be generated relatively rapidly on small computer resources. The geometry, wavelengths, and times can be varied to meet specific user requirements. As part of the SSGM team effort, we are developing the required capability to meet the application needs of the SATKA community.

5.0 ACKNOWLEDGEMENTS

This work is supported by SDIO and NRL under NRL prime contract N00014-89-C-2283, sub-contract to PRA 1805-89-CPF-002. We are grateful for the help and advice given by Dr. Harry Heckathorn of NRL and the several scientists at GL that support the development of the fundamental atmospheric codes.

6.0 REFERENCES

Anding, D. Strategic Scene Generation Model Prototype (SSGMP) Reference Manual, p.65, 1988.

Archer, D.H., Tarr, P.W., "Final Report on Auroral Simulation Effects - Haes Report No. 62", DNA-4275, (1977).

Armstrong, R.A., Hendrick, R., Saunders, E., and McKenzie, S.M., "Nuclear Disturbed Earthlimb, Radiance Structure, Uncertainties and Recommendations" (Manuscipt in Draft), (1989).

Harang, L., "The Aurorae", Wiley and Sons, New York (1951).

Hines, C.O., "Internal Atmospheric Gravity Waves at Ionospheric Heights", Can. J. Phys. 38, 1441 (1960).

Humphrey, C.H., Nadile, R.M., Philbrick, C.R., Smith, D.R., "Atmospheric Infrared Radiance Variability", Chap. 2, Current High Altitude Infrared Radiance Model, T. Degges, AFGL-TR-81-0207, 1981.

Kennealy, J.P., Downer, S.B.,Larkin, R.J., and Moratz, T.J., "ARCHON-22 Annual Report", MRC-NSH-R-89-0001, (1989).

Kilb, R., and Wittwer, L., Private Communications, (1986).

Kneizys, F.X., Shettle, E.P., Gallery, W.O., Chetwynd, J.H., Abreu, L.W., Selby, J.E.A., Clough, S.A., Fenn, R.W., "Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 6", AFGL-TR-83-0187, 1983.

McKenzie, S.M., Kennealy, J.P., and Armstrong, R.A., "MRC Spectral Modelling Codes: DOUBPI and SINGLET", MRC-NSH-R-87-0004, (1987).

Sharma, R.D, Ratkowski, A.J., Sundberg, R.L., Duff, J.W., Bernstein, L.S., Acharya, P.K., Gruninger, J.H., Robinson, D.C., Healey, R.J., "Description of SHARC, The Strategic High Altitude Radiance Code, GL-TR-89-0229, 1989.

Smith, D., Fritts, D., and VanZandt, T., J. "Evidence for a Saturated Spectrum of Atmospheric Gravity Waves", Atm.Sci., 44, (10), 1404 (1987).

Stephens, T.L., Strategic Scene Generation Model Prototype (SSGMP) Reference Manual, p.67, 1988.

Wintersteiner, P.P., Sharma, R.D., "Update of an Efficient Computer Code (NLTE) to Calculate Emission and Transmission of Radiation Through Non Equilibrium Atmospheres", AFGL-TR-85-0240, 1985.

NUCLEAR BACKGROUNDS FOR SSGM

January 1990

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ABSTRACT

The structured infrared backgrounds created by nuclear detonations in the atmosphere are an important element of the scenes generated by the SSGM code. SSGM utilizes state-of-the science Defense Nuclear Agency (DNA) computer codes to provide nuclear disturbance caused environments. The SSGM Prototype was delivered with a data base for a single nuclear burst (10 Megatons at 120 km) in three spectral bands (SWIR, MWIR and LWIR). The data base was generated with the DNA NORSE code.

The Baseline SSGM will have a more robust capability to generate Nuclear Backgrounds with the incorporation of the DNA PEM code into its run-time generation capabilities. PEM (Propagation Engagement Module) calculates propagation environments from a NORSE-generated data base. NORSE-generated data bases will be included in the SSGM element library. PEM will be exercised by SSGM to create scenario specific background radiance maps and opacity maps which will be stored in the run-time library. Initially Version 3.3 of PEM will be installed in SSGM. The architecture will be flexible so that future PEM versions and database upgrades can be included straighforwardly in SSGM.

The impact of bright nuclear backgrounds on sensors is highly dependent on the spatial and temporal structure exhibited by those backgrounds. The DNA produced STRCTR module, which modulates deterministic backgrounds with small scale temporally correlated spatial structure, has been incorporated into SSGM. STRCTR will be extended to support several of the phenomena modeled in SSGM.

In the paper, high resolution examples of structured nuclear images will be shown. Also the range of nuclear burst scenarios that will be handled in the baseline SSGM will be indicated.

Introduction

The structured infrared backgrounds created by nuclear detonations in the atmosphere are an important element of the scenes generated by the Strategic Scene Generation Model (SSGM). Fig-

ure 1 shows the various phenomenological regions that must be treated in SSGM. SSGM utilizes state-of-the-science Defense Nuclear Agency (DNA) computer codes to provide these nuclear disturbance caused environments. This paper will provide an overview of the nuclear environment models used by SSGM for either online calculations of the background or used off-line to create pre-calculated data bases. Also described is the software implementation of the nuclear capability in SSGM and a discussion of the small scale stochastic structure model used in SSGM not only for nuclear scenes, but for other phenomenological regions as well.

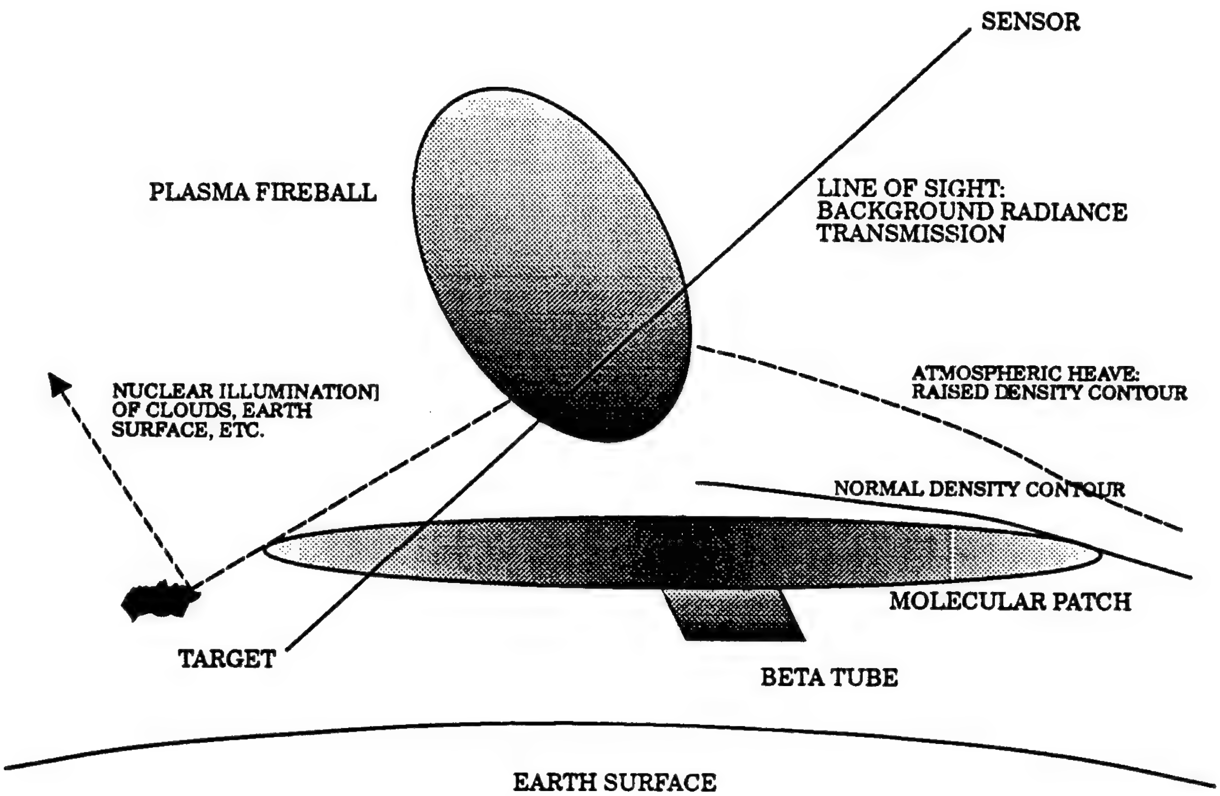


Figure 1. Nuclear Model Treatments.

Nuclear Environment Models

The three nuclear environment models used by SSGM are NORSE (Nuclear Optical and Radar System Effects), PEM (Propagation Engagement Module), and IRSim (Infrared Simulation). These codes model the nuclear environments encountered by IR sensors operating in the presence

of nuclear bursts and each one fills an important, although separate niche for SDI code requirements.

NORSE has the recognized state-of-the-science nuclear background prediction capability. NORSE is a large complex code which requires considerable expertise to be exercised correctly. The code also requires a CRAY-class computer for operation due to the code size and complexity of the calculations performed. NORSE is an engineering level code, which places it between first-principles physics codes and simpler, fast running engagement level codes which can be incorporated into systems analysis codes. Both PEM and IRSim derive their capabilities from NORSE (Figure 2).

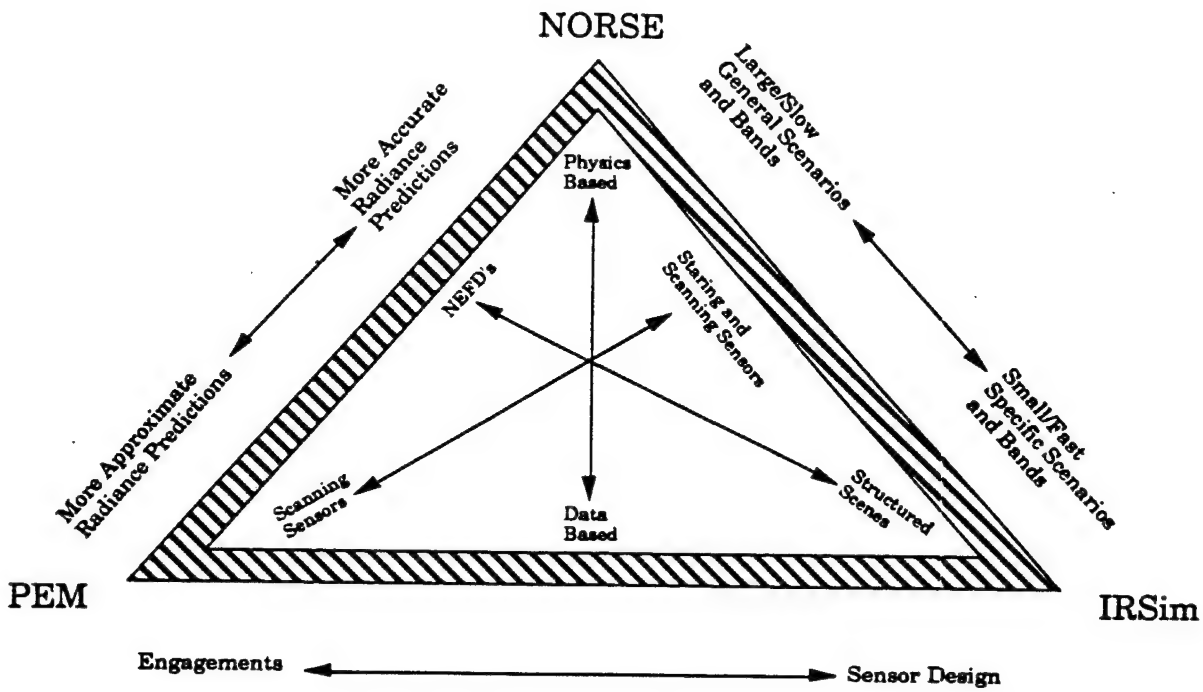


Figure 2. Nuclear Model Relationships.

PEM uses NORSE parametrically created data bases of propagation and dimensional quantities[1]. These values are stored in binary direct access files which allows for fast execution and

[1]William Blackwell, Jr., et al., "The NORSE Manual, Volume 3C-2: Propagation Engagement Module (PEM)", (Huntsville, AL: Physical Research, Inc., 1988).

versatility in application. PEM is designed to access the NORSE generated data base and provide an answer in much less time and using far fewer lines of code than NORSE. Also, PEM is easily transportable to different machines, and has been successfully operated on CYBER, CRAY, VAX, IBM PC compatibles, and Macintosh computers.

IRSim is another DNA sponsored code which is derived from NORSE. Instead of using large external data files like PEM, IRSim makes use of analytical radiance models (ARMs). ARMs are comprised of multivariate curve fits to NORSE predictions that represent the spatial distribution of the plasma, molecular, and beta contributions to in-band radiance from nuclear disturbed backgrounds. As stated above, these three codes perform complementary roles. Table 1 illustrates the capabilities of NORSE, PEM, and IRSim. The code's capabilities is of course a function of its complexity. Figure 3 shows a comparison of the relative run times of the three codes for a given case. It is seen that PEM is approximately 1000 times faster than NORSE, while IRSim is about 100 times faster than PEM (100,000 times faster than NORSE).

Table 1. NORSE, PEM, IRSim Capabilities.

	NORSE	PEM	IRSim
OPTICS	X	X	X
RADAR	X	X	
PHENOMENOLOGY	X		
MULTI-BURST	X	X	
MEAN BACKGROUND	X	X	X
STRUCTURED BACKGROUND			X
RADIATION ENVIRONMENT	X		
SENSOR RESPONSE	X	X	
ARBITRARY GEOMETRY	X	X	
POINT PROPERTIES	X		
TARGET MODELS	X	X	
GRAPHICS	X	X	X
SCENE GENERATION	X	X	X
RESTART CAPABILITY	X		
ARBITRARY BANDS	X	X	

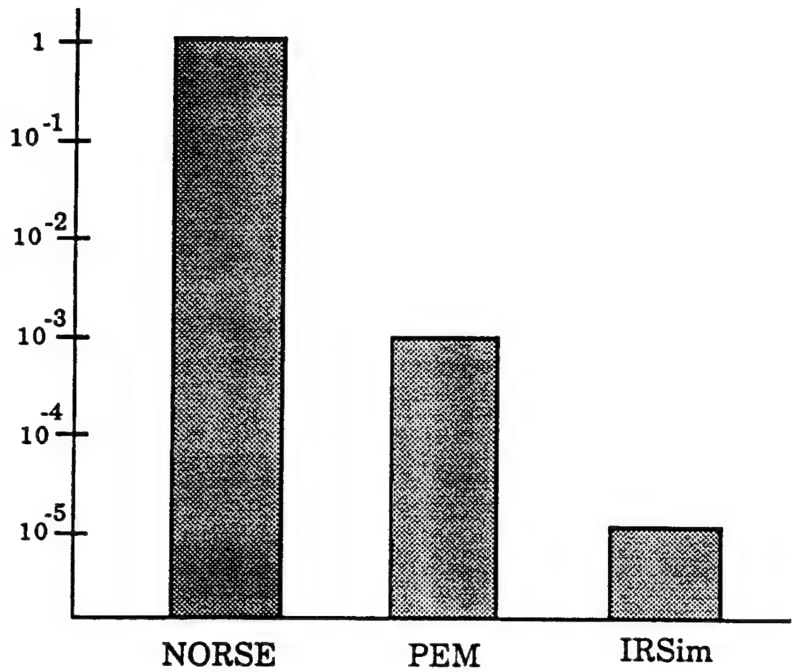


Figure 3. Run Time Comparison

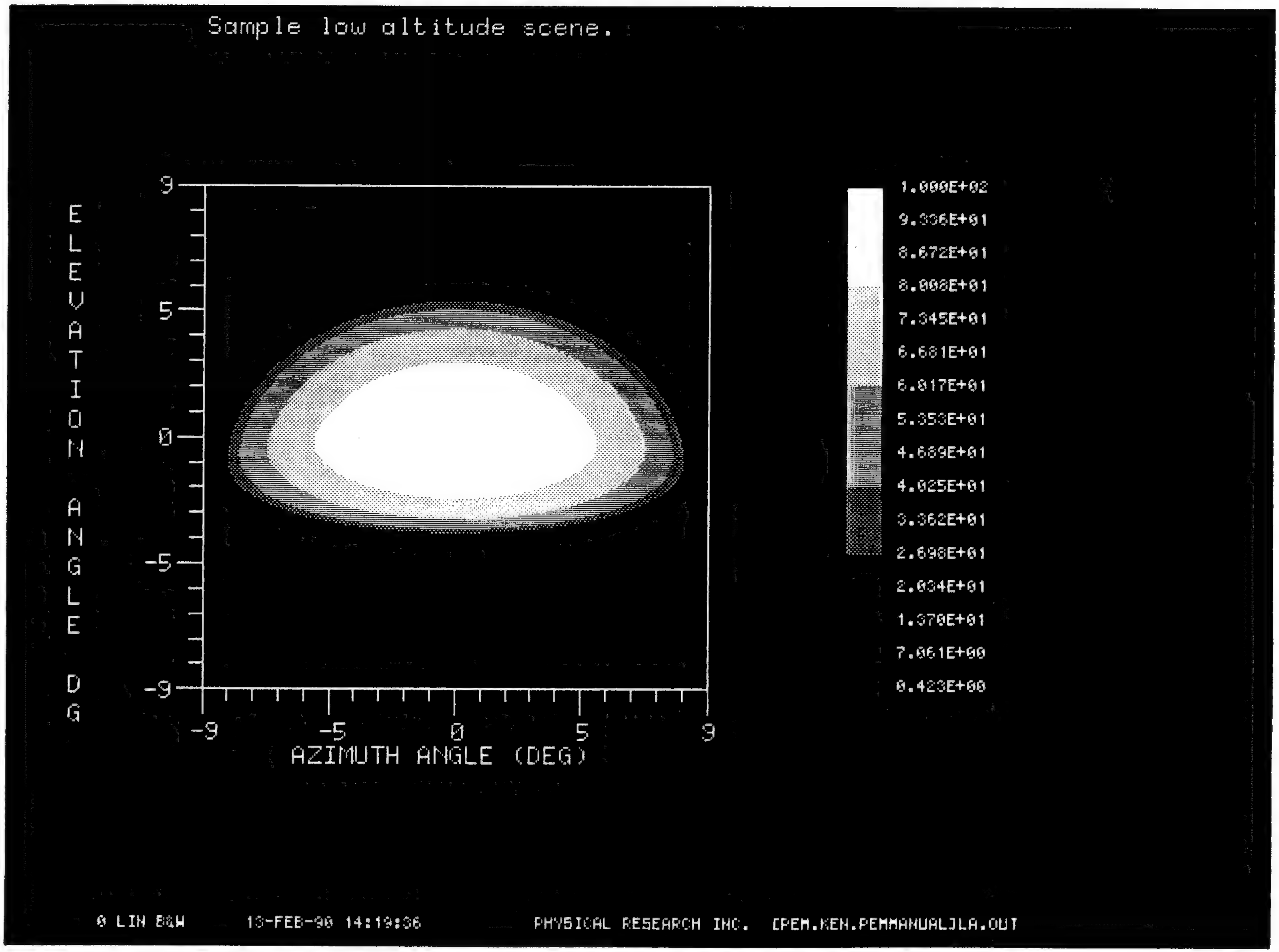
Example Scenes

The first example two-dimensional in-band radiance scene shown in Figure 4 is a deterministic (small scale stochastic structurenot included) PEM scene. The one-megaton yield detonation occurs at 45 km and the sensor is positioned coaltitude with the detonation point and 50 km to the east. The sensor's boresight is 10 km above the detonation point (Figure 5).

The second example is that of a high altitude detonation. The geometry of this case is depicted in Figure 6. This is an exemplar scenario for a synchronous orbit sensor viewing a mid-latitude bust. Figure 7 shows the 2-D radiance scene. Apparent in this scene are the phenomenological regions diagrammed in Figure 1.

SSGM Nuclear Model

The nuclear runtime generator (NRTG) for use in SSGM will be a modified version of PEM, the DNA sponsored code which bases its calculations upon a NORSE generated data base. Figure 8 illustrates the functional flow of the baseline SSGM and how the PEM code fits into the program. During the Sequence Definition phase of SSGM, the determination is made as to whether PEM calculations are needed to further populate the run time library (RTL) with additional scenes for the scenario of interest. During the Run-Time Generation phase, the PEM code is executed to create the scenes defined by Sequence Definition. This is accomplished by running PEM as a spawned


Sample low altitude scene.
ELEVATION ANGLE DG
9
5
0
-5
-9
-9
-5
0
5
9
AZIMUTH ANGLE (DEG)
1.000E+02
9.336E+01
8.672E+01
8.008E+01
7.345E+01
6.681E+01
6.017E+01
5.353E+01
4.689E+01
4.025E+01
3.362E+01
2.698E+01
2.034E+01
1.370E+01
7.061E+00
0.423E+00
0 LIN B&W
13-FEB-90 14:19:36
PHYSICAL RESEARCH INC.
[PEM.KEN.PEMMANUAL]LA.OUT

process, allowing the user to leave the RTG phase and come back for the Frame Generation phase after the RTL has been populated (hours or days later).

Figure 9 shows the architecture of the SSGM nuclear module[2]. RTGNUC is the nuclear phenomenology model "driver". This is a top level driver which invokes the NRTG for SSGM. PEMINP is the submodule which creates the inputs required by the PEM code in its role as the SSGM NRTG. PEMINP selects the times and locations of the pixels for the NRTG to produce two-dimensional variable-grid radiance maps that are stored in the SSGM RTL (Figure 10). The module PEMSGD performs as the run-time generator of nuclear environments in the baseline SSGM. PEMOPT is the optics module adapted directly from PEM.

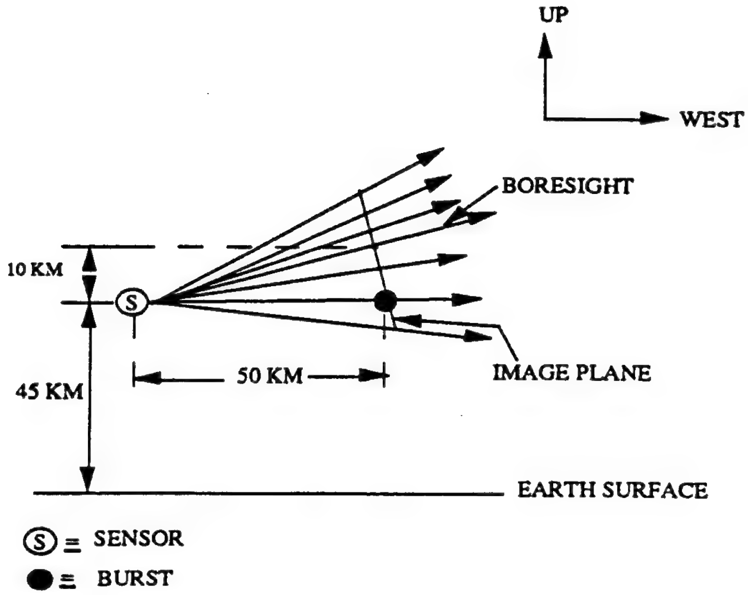


Figure 5. Low Altitude Scene Geometry.

PEMXP and NUCLUM are new modules that will calculate the atmospheric heave conditions and nuclear illumination of clouds, respectively.

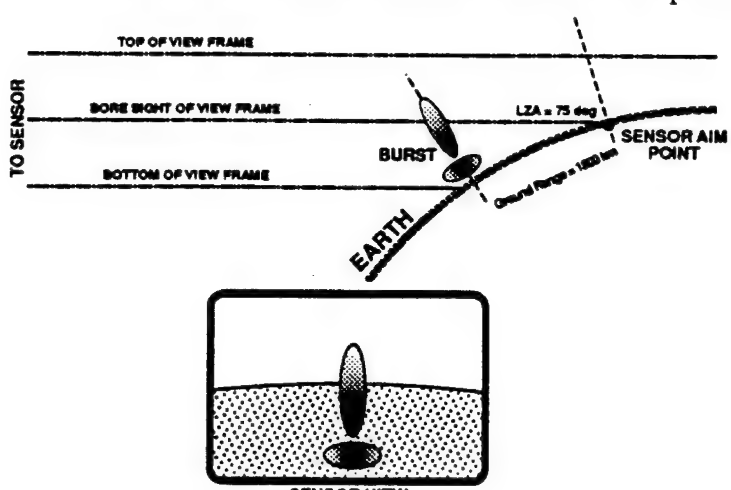
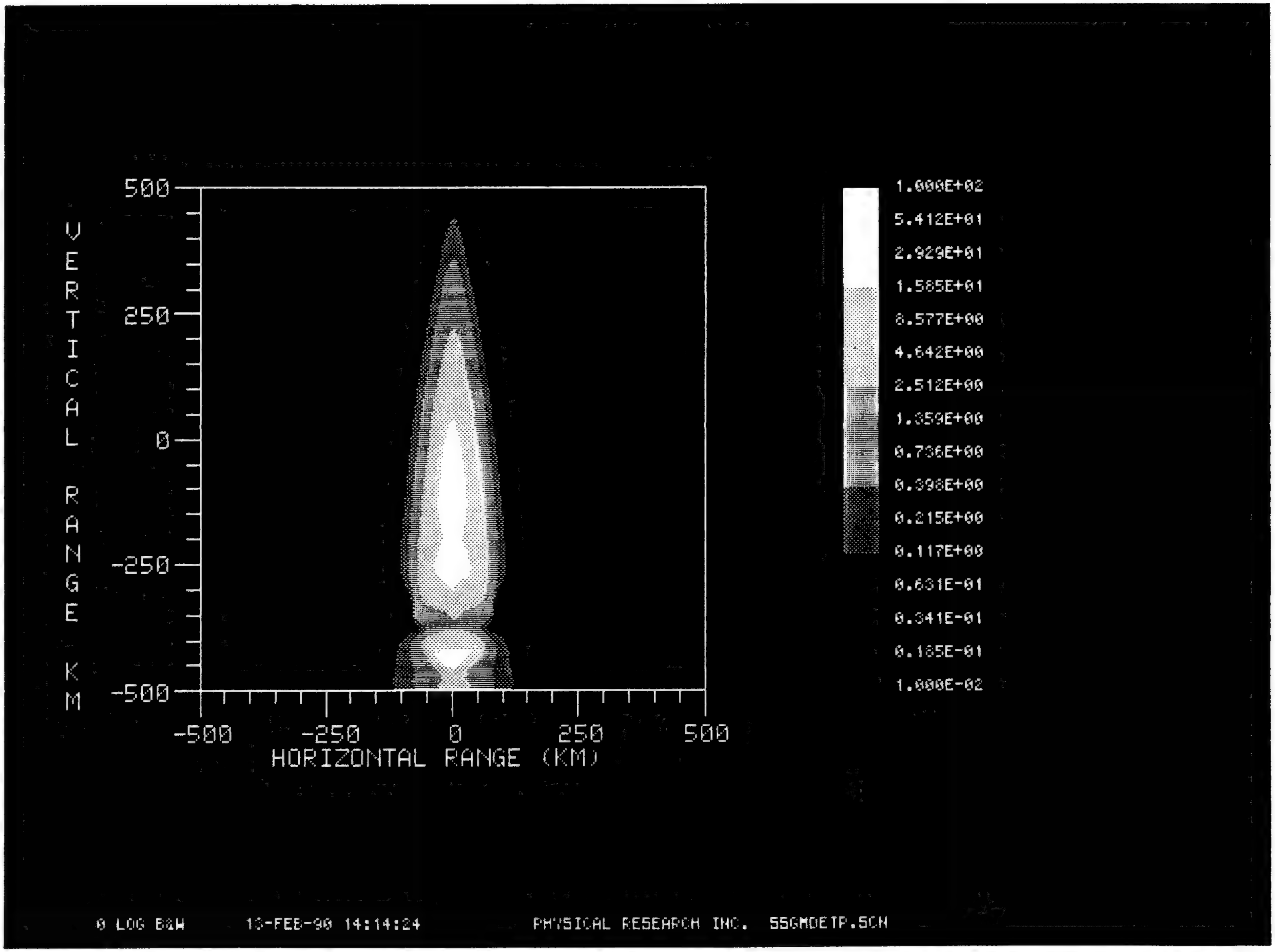


Figure 6. High Altitude Scene Geometry.

[2]David C. Anding, "Baseline Design for an Operational Strategic Scene Generation Model", (La Jolla, CA: Photon Research Associates, 1988).


VERTICAL RANGE KM
500
250
0
-250
-500
-500
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0
250
500
HORIZONTAL RANGE (KM)
1.000E+02
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2.929E+01
1.585E+01
8.577E+00
4.642E+00
2.512E+00
1.359E+00
0.736E+00
0.398E+00
0.215E+00
0.117E+00
0.631E-01
0.341E-01
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0 LOG B&W
13-FEB-90 14:14:24
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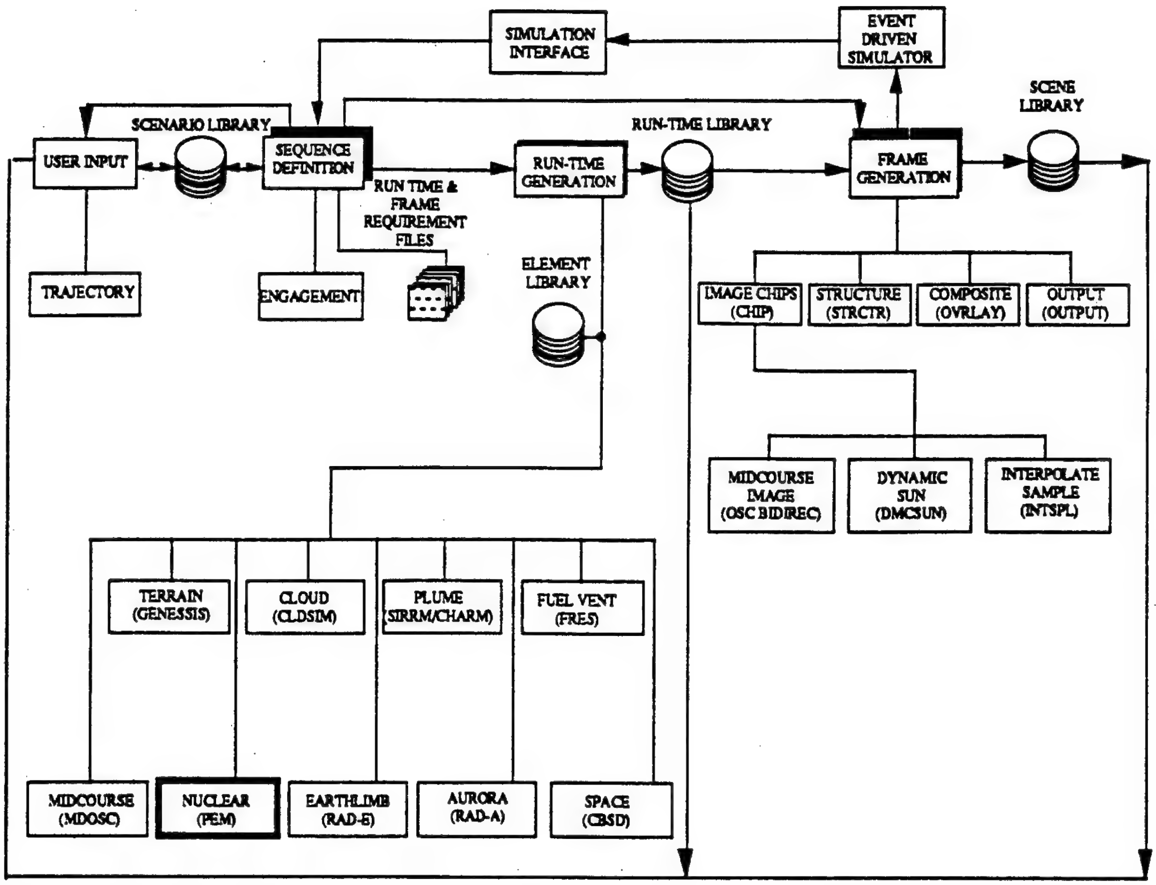


Figure 8. Baseline SSGM Functional Flow.

PEMFMT reformats the output of the NRTG into a form required for use in the SSGM RTL and performs the installation.

The data flow between the SSGM and NRTG modules is shown in Figure 11. The user supplies to the NRTG his requirements through the USRINP module. PEMINP will determine from the input scenario whether nuclear phenomenology should be included in the output. If nuclear contributions to the background radiance is deemed necessary, PEMINP will also choose where the points on the sample plane are to be placed. The sites of these points are chosen in a manner so to provide the best possible spatial resolution of the nuclear disturbed region without creating RTL files that are unnecessarily large and without taking too much time during the NRTG process (Figure 12).

The SSGM element library will contain the NRTG (PEM) data bases. As shown in Figure 11, the dimensional information should be available to both PEMINP and PEMSGD. PEMINP requires the information in order to make its decisions about performing the calculations mentioned earlier. PEMSGD needs both the dimensional and propagational quantities (i.e., volume emission and absorption coefficients) in order to perform the mean background radiance and transmission calculations. Also included in the output from PEMSGD are the structure parameters and radiance standard deviation values needed to perform the stochastic structure realizations with the STRCTR module in the Frame Generation process. PEMFMT at last takes the NRTG output and places it into the SSGM RTL. Because each phenomenology region must be structured independently, PEMFMT writes out separate RTL files for the plasma, molecular, and beta tube regions.

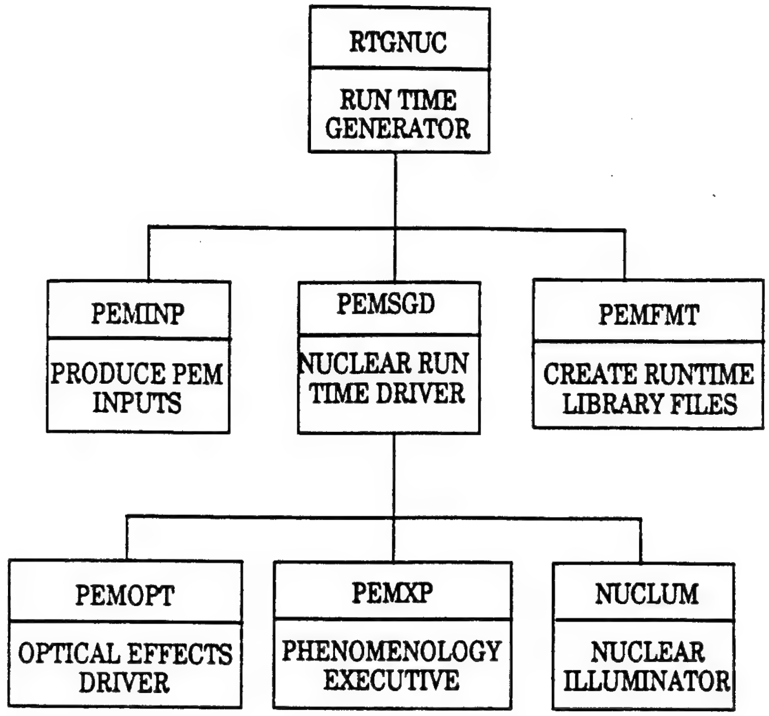


Figure 9. SSGM Nuclear Architecture.

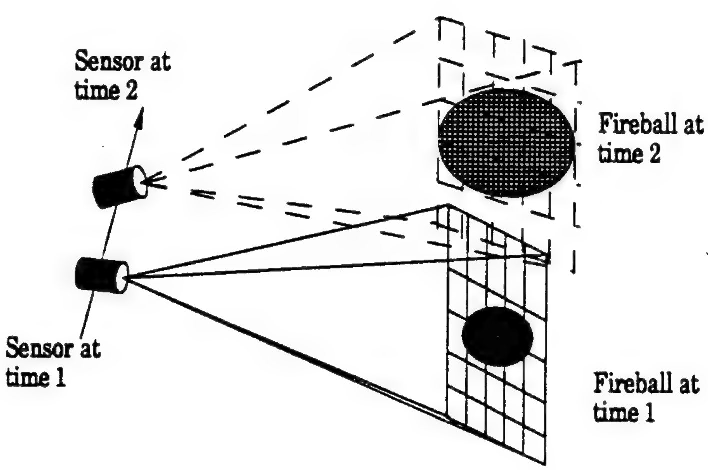


Figure 10. Run-Time Library View Frames for Interpolation.

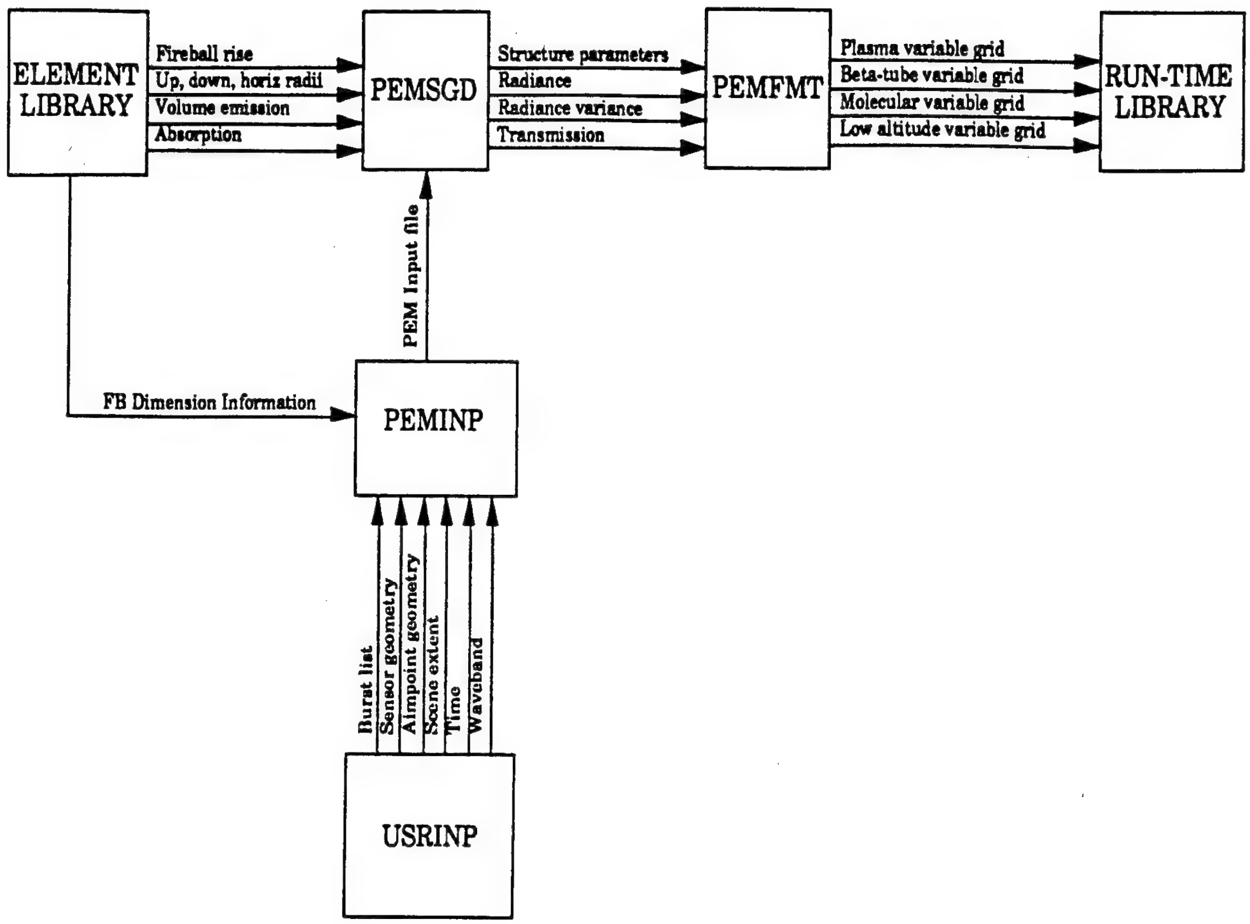
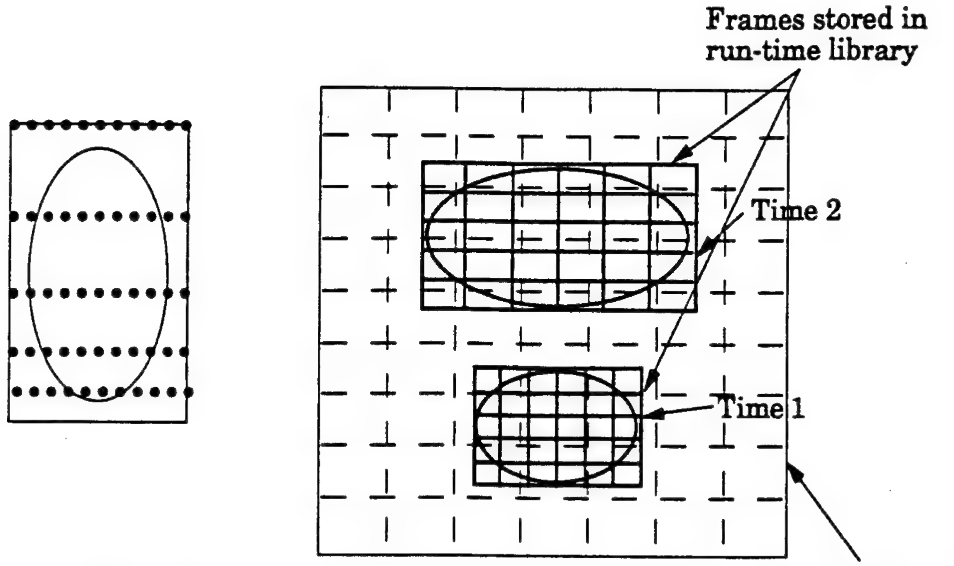


Figure 11. Nuclear Data Flow.

SSGM Nuclear Data Base Generation

Table 2 shows the various nuclear data bases to be included in the SSGM Element Library. These data bases are created off-line by parametric execution of the NORSE code. There will be both a generic PEM data base and a series of SDIO system specific data bases included. Also, there will be a single burst atmospheric heave data base for the PEMXP module of the NRTG (Figure 9). This data base will consist of NORSE predictions of mass density point calculations for intermediate and high altitude bursts. NORSE will also be used to create the nuclear illuminator data base for the NUCLUM module.



• PEMINP chooses points on sample plane

• Interpolated arrays register with final scene

Figure 12. PEMINP Operation.

Structure Model

Nuclear phenomena, as well as many other environments (both artificial and natural) exhibit both large scale deterministic and small scale stochastic structure. The inclusion of the small scale structure is critical to the tasks of evaluating system performance, since it is often true that even when the mean (deterministic) background is not bright enough to hinder performance, upon inclusion of the small scale structure there is significant performance degradation.

The Structure Module (STRCTR) in SSGM combines the realization of small scale stochastic structure with the deterministic scenes generated by Image Chips from the phenomenology model Run-Time Library (RTL) data base. Each phenomenology's RTL files provide parameters which describe the statistics of the structure. The stochastic structure module gives a two-dimensional radiance field whose underlying distribution is Gaussian. The correlation of the Gaussian field is

Table 2. Baseline SSGM DB Generation

- IR Data Bases
  - Generic PEM 3.2:

Low Alt.	Burst alt. range	10 to 90 km
	Burst yield range	10 kt to 10 MT
	Wavelength coverage	2 to 25 μ
	Wavelength resolu.	5% of wavelength
	Burst age	0.1 to 300 sec.
High Alt	Burst alt. range	90 to 700 km
	Burst yield range	100 kt to 10 MT
	Wavelength coverage	2 to 25 μ
	Wavelength resolu.	30% of wavelength
	Burst age	1 to 300 sec.

  - SSGM Specific: Low/High alt. data bases (total of 5 dB's) for selected scenarios
    - Downloading
    - Limb Viewing
    - Airborne sensors
    - Exoatmospheric interceptor
    - Endoatmospheric interceptor

- IRSim-B, -M
  - Multi MT/120 km
    SWIR, MWIR, LWIR
    Band Coverage
    ~ 10% of wavelength

- Nuclear illuminator dB.

- Nuclear heave dB. All times, one burst

governed by a two-dimensional Power Density Spectrum (PSD) shown in Figure 13. The mean radiance and the variance may vary from point to point.

Figure 14 gives the stochastic structure generator architecture. The primary structure routine is STRCTR. STRCTR calls STOCHS to generate random Gaussian two-dimensional structure arrays with specified statistics. STRCTR then maps the structure arrays onto the view-frame arrays as defined by Sequence Definition. Temporal decorrelation of the stochastic structure is accounted for by translating, expanding, and elongating the structure during the mapping process.

The standard two-dimensional structure map generated by STOCHS is a random field with Gaussian statistics, zero-mean, unit-variance and has a specified power spectral density (PSD) function. The functional flow for generating a standard structure array in STOCHS is shown in

One PSD used for all environments (aurora, clouds, nuclear, etc.)

$$PSD(k_x, k_y) = \frac{A}{\left[1+(k_xL_x)^2+(k_yL_y)^2+ k_xk_yL_{xy}\right]^{S_i}\left[1+(k_xl_x)^2 +(k_yL_y)^2+ k_xk_yl_{xy}\right]^{S_t - S_i}}$$

where

k_x , k_y	= Spatial wave numbers
L_x , L_y	= Structure outer scale lengths (km/rad)
l_x, l_y	= Structure freezing scale lengths (km/rad)
L_{xy}, l_{xy}	= Cross terms
S_i	= Intermediate spectral index
S_t	= Transition spectral index
A	= Normalizing constant

$$\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} PSD(k_x,k_y)dk_xdk_y = 1$$

Figure 13. Structure PSD.

Figure 15 and is described as follows:

(1) STOCHS generates an array of Fourier coefficients which are transformed into the spatial domain for subsequent mapping by STRCTR. The Fourier coefficient array has dimensions m by n (where both m and n are powers of 2). Each Fourier coefficient is a complex number with real and imaginary components chosen independently from a Gaussian distribution. While there are 2mn Fourier coefficients, only mn of them are independent (so that the transformation into the spatial domain is real rather than complex). Based on a supplied random number seed, STOCHS generates the mn independent Fourier coefficients. The specified power spectral density (PSD) function, normalized to unit total power, is evaluated at each Fourier component frequency, and the zero-mean, unit-variance Gaussian deviate is multiplied by this value. The complete table of 2mn Fourier coefficients is established using symmetry principles.

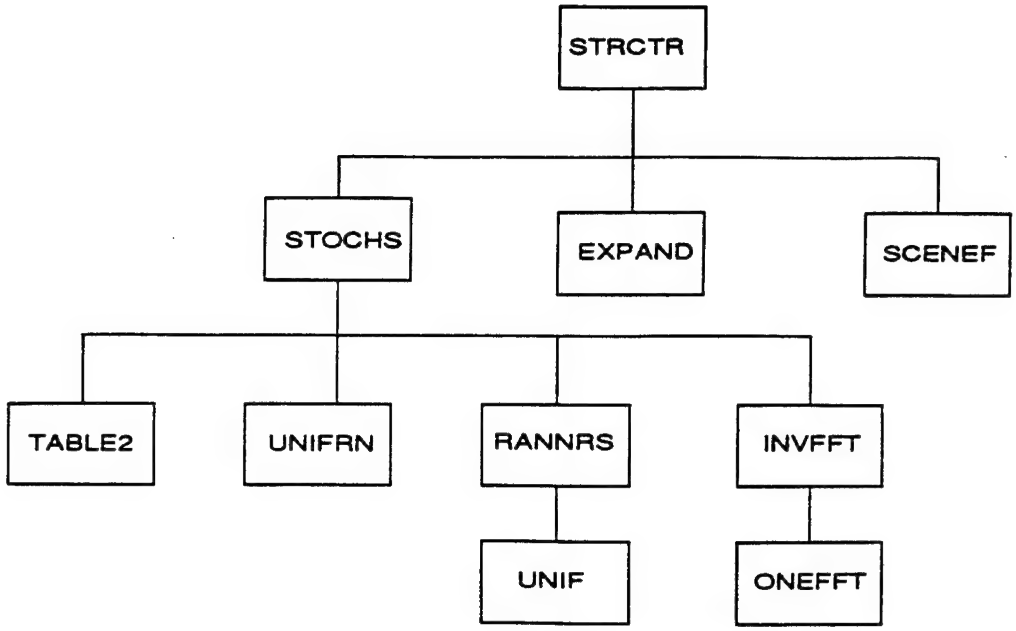


Figure 14. Stochastic Structure Generator Architecture.

(2) An inverse fast-Fourier transform (FFT) is performed on the array of Fourier coefficients. The result is a standard radiance map with Gaussian statistics, unit variance, zero mean and the proper PSD.

The development of a structured scene in the sensor viewing frame is illustrated in Figure 16. A view-frame grid is formed covering the sensor field of regard at a specific time. The deterministic image of radiance for a particular scene element, projected onto the view-frame grid, is supplied to STRCTR. A separate stochastic structure grid is generated by calling STOCHS. The same structure grid may be used for several look times and for multiple spectral bands. A portion of the structure grid is mapped onto the view-frame grid at each specified time. Through a time dependence in the mapping algorithm, the realization of spatial structure is allowed to move across the view frame, to expand and to elongate (as in the growth of nuclear striations along the Earth's magnetic field lines). STRCTR is constructed so that additional mapping algorithms can be added as required by the physics of each phenomenon.

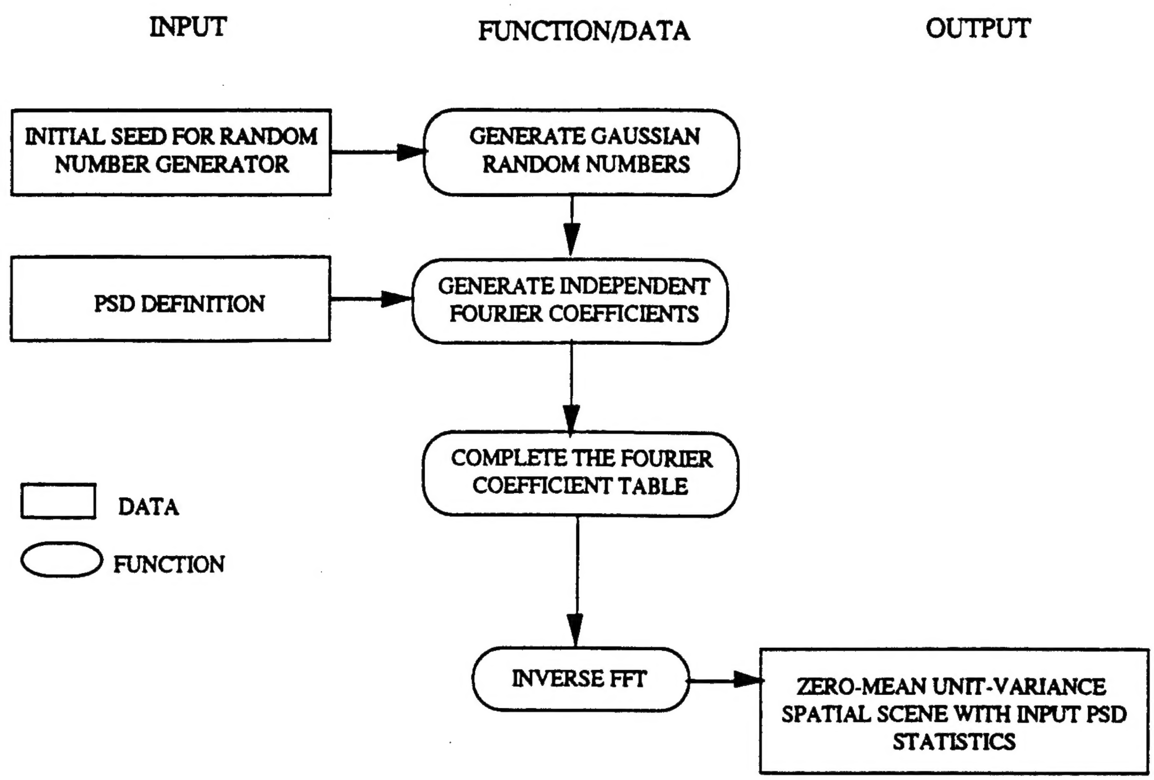


Figure 15. STOCHS Stochastic Structrure Primitive.

The position of the "early time" and "late time" view-frame outlines on the stochastic structure grid (Figure 16) show that the structure map has moved and that the size of the structure has expanded relative to the fixed size of the view frame. (The latter is shown by decreasing the size of the view frame relative to the structure grid.)

Also shown in Figure 16 is a nested grid in the structure array, which is adopted for computational efficiency. Typically a 256-by-256 to 1024-by-1024 array can be handled easily by present-day computers. (The limiting factor is the requirement that the entire complex array fit into memory at one time during the inverse FFT process.) By embedding, for example, a 256-by-256 array within a 16-by-16 array (so that we have 16x16 replications of the 256-by-256 array, each modified by the larger grid), we achieve the dynamic range of a 4096-by-4096 array with a modest loss of statistical

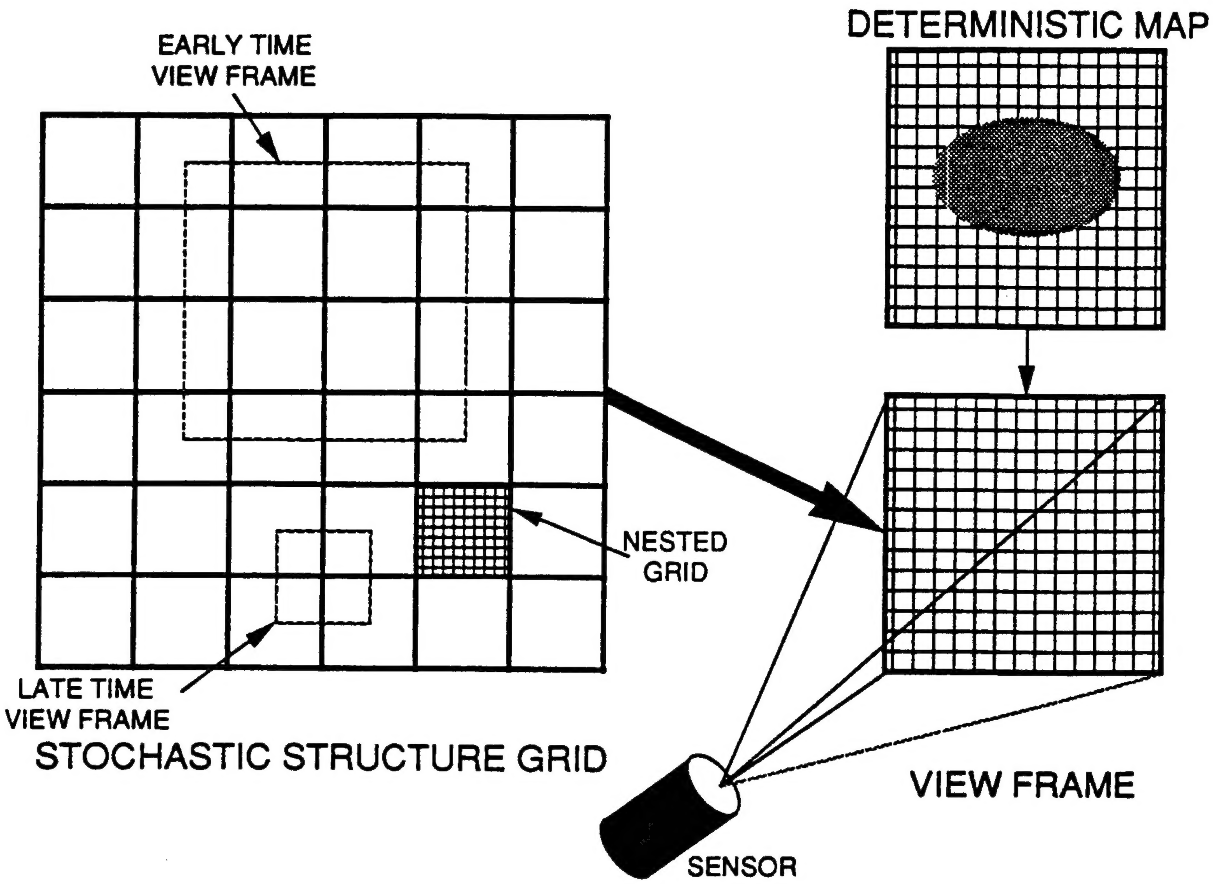


Figure 16. Mapping of Structure Grid Onto View Frame.

independence. Both the small scale and large scale structure grid will be generated with STOCHS. The specific size of the high resolution embedded array will be determined by the largest size that can be conveniently handled by the computer, the low resolution grid by the spatial extent required to span the field of regard.

The functional flow of the STRCTR routine is shown in Figure 17. The first step is to call STOCHS to create the structure grid for the first time and band. When the nested grid approach is required, STOCHS will be called twice. The nested structure array (actually a pair of smaller arrays) is saved. If a temporal or band correlation is required, that is performed next. The correlation parameters are supplied by the phenomenology modules; in general, they will have a spatial fre-

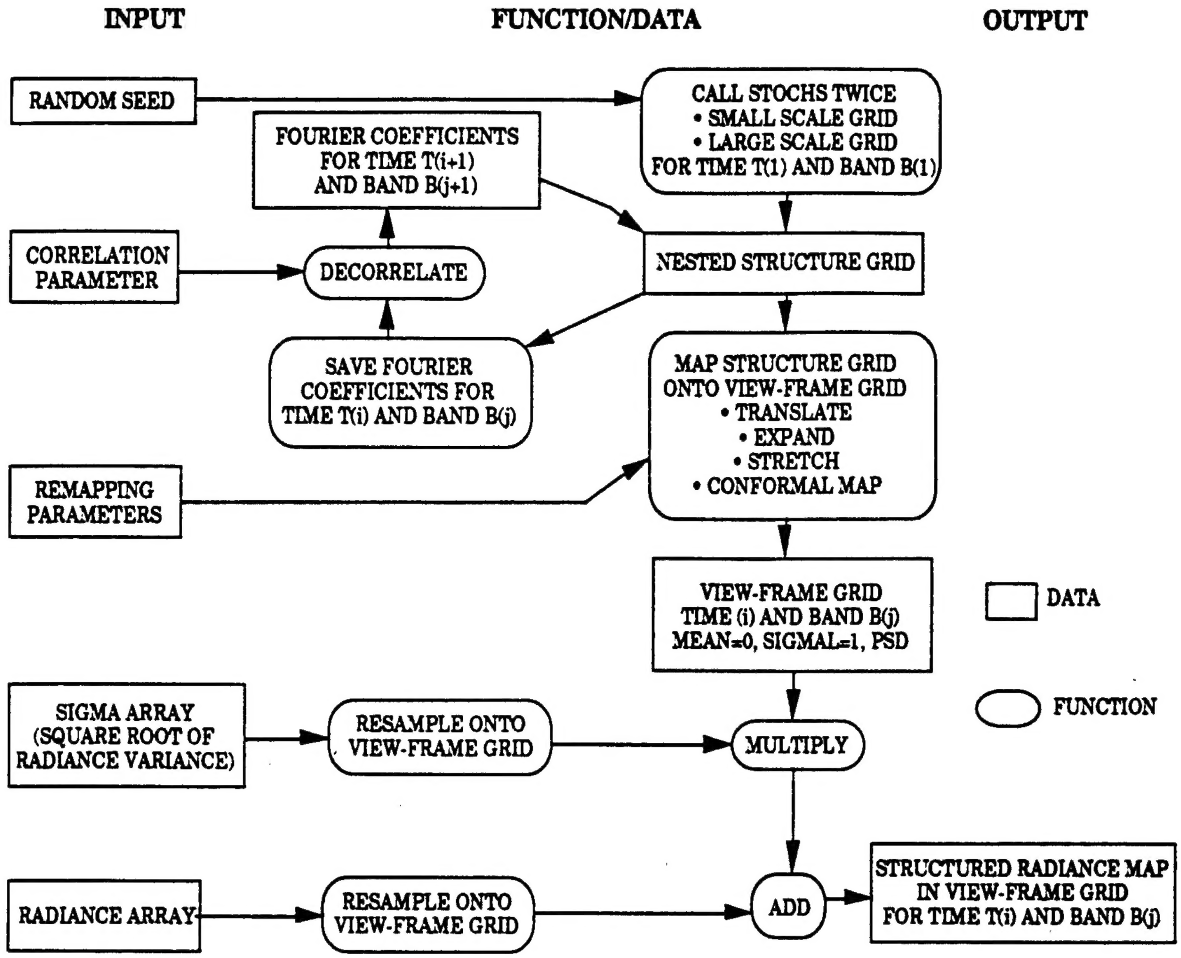


Figure 17. STRCTR (Stochastic Structure Generator) Functional Flow.

quency dependence. For example, large scale structure may decorrelate more slowly than small scale structure. The decorrelation works as follows:

(1) The original Fourier coefficients are recalled as array F1.

(2) A new independent array of Fourier coefficients is generated as array Fs.

(3) An array C of correlation coefficients is developed from the spatial-frequency dependent correlation function supplied by the phenomenology module.

(4) The array

$$F2(i, j) = C(i, J)\ F1(i, j) + [1 - C^2(i, j)]^{1/2}\ Fs(i, j)$$

is the Fourier table for the second time (or band). This process is continued for all output frames and each frame is inverse transformed into the spatial domain. STRCTR maps the structure grid for each frame onto the view-frame grid, as shown in Figure 16, using the remapping parameters supplied by the phenomenology modules. At this point, structure motion and growth have been accounted for by remapping, while statistical evolution has been accounted for in the decorrelation process, with the combined result mapped into the view frame.

The last step is to combined the structured scene with the deterministic scene. This is accomplished in the functional elements "MULTIPLY" and "ADD". The deterministic map includes arrays of radiance and of the standard deviation. These arrays are at the resolution of the view-frame grid. The structure array is then multiplied by the standard deviation array (to give the correct variance) and added to the radiance array (to give the correct mean). The multiplications and additions are performed on a pixel-by-pixel basis in the view frame grid. The result is a time-series of properly structured and correlated radiance maps in each band.